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NASA TECHNICAL MEMORANDUM

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N81-22065

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G3/12 42133

MATERIALS PROCESSING IN SPACE (MPS) PROGRAM DESCRIPTION

By Materials Processing in Space Projects Office

April 1981

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ACCESS DEPT.

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

MSFC - Form 3190 (Rev June 1971)

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MATERIALS PROCESSING IN SPACE (MPS)
PROGRAM DESCRIPTION

Introduction

The primary motivation of the MPS program is to stimulate and accommodate the scientific and commercial utilization of the unique environments of space for material science and engineering. The elimination of the pervasive influences of gravity on Earth-based materials production affords opportunities for understanding and improving ground-based methods or, if practical and economical, producing select materials in space which, typically, would be of low volume, high value commercial interest. Additionally, the unlimited, if not "hard," vacuum of space affords equally interesting opportunities for material processing. To evolve the commercialization of MPS, the program is structured (1) to establish and demonstrate the scientific principles associated with gravitational effects on processes used in the production of common materials, (2) to develop the technology to accommodate scientific and commercial pursuits in space, and (3) to establish the legal and managerial framework to implement commercial ventures.

The interest in the behavior of materials in low gravity grew out of a variety of disciplines. The earliest and most compelling need to understand fluid behavior in low gravity grew out of the necessity to manage liquid propellants in orbiting spacecraft. This effort spawned a number of excellent studies of the surface tension and inertia of fluids in partially filled containers. Perhaps the first requirement to understand the solidification process in a low-g environment originated from the development of phase change thermal control systems. Studies on the erection of large structures in space prompted questions concerning the behavior of metals during welding and brazing processes in low gravity. From such spacecraft oriented investigations, it was recognized that the low-gravity environment offered unique advantages for processing materials in their molten state, and a number of manufacturing processes to be carried out in space were postulated for the production of improved or unique products.

Apollo Experiments

Several demonstration experiments were carried out during the Apollo flights. It was shown that in the absence of gravity, heat flow in fluids was predominantly by conduction. It was also found that the only observed flow in a simple static electrophoresis demonstration experiment resulted from electroosmosis. Due to the absence of convection, low temperature

casting of an immiscible model system, paraffin and sodium acetate, produced a dispersion of sodium acetate globules ranging from microns to millimeters in diameter.

Skylab and Apollo-Soyuz Experiments

Skylab offered the first opportunity to carry out extensive experiments in materials science in space. A total of 15 experiments and 9 demonstrations were conducted. The complement of experiments included crystal growth, metal composites, eutectics, welding and brazing, fluid effects, and combustion processes.

The Apollo-Soyuz Test Project (ASTP) carried 12 materials science experiments and 3 demonstrations. Several of these were similar to the Skylab experiments where verification and refinements were required. In addition, two electrophoresis biological separations were attempted on the ASTP.

Sounding Rocket Experiments

The Space Processing Applications Rocket (SPAR) project was established to provide continuity between the ASTP flight and the advent of Shuttle. This rocket program provides a number of short duration (5-7 minutes) flight opportunities for investigators to pursue their research in low-gravity phenomena and to develop concepts and techniques to be used later in Shuttle flights. To date, eight SPAR rockets have flown experiments and two additional missions are expected during 1981. Figure 1 depicts a typical sounding rocket (SPAR) payload.

The low-gravity environment on SPAR was found to be an excellent interim tool for meaningful research in material science since levels of 10^{-5} to 10^{-6}g were maintained during the coast period. However, the short duration and harsh launch environment, including spin-up and spin-down, provide a real challenge for experiment design and limit what can be accomplished scientifically. Despite these limitations, the sounding rocket program has been beneficial for accommodating a cadre of experimentalists interested in conducting materials research under low-gravity conditions. The scientific goals have been worthy and many of the research ideas to be carried out on the Shuttle emerged from these experiments. Considerable experience has been gained in developing and testing new hardware, and a significant inventory of off-the-shelf hardware has been built up that can also be used to conduct longer duration experiments which will be flown on a space-available basis during Shuttle operations. Experience in developing low-cost hardware and experiments has been a vital product of this program. The sounding rocket is expected to continue to be an important experimental capability in the MPS program for several years.

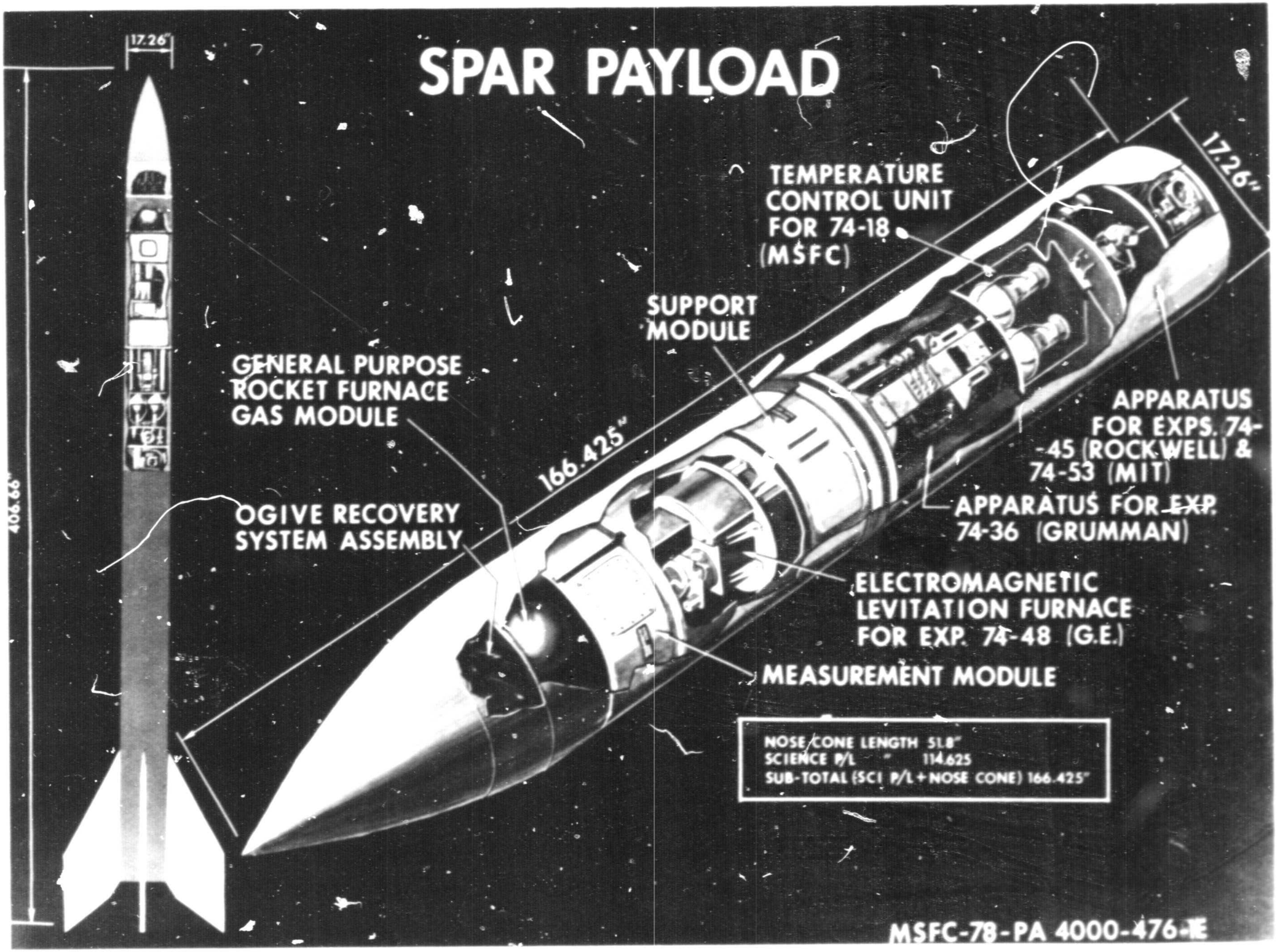
SPAR PAYLOAD
17.26"
406.66"
166.425"
17.26"
TEMPERATURE CONTROL UNIT FOR 74-18 (MSFC)
SUPPORT MODULE
GENERAL PURPOSE ROCKET FURNACE GAS MODULE
OGIVE RECOVERY SYSTEM ASSEMBLY
APPARATUS FOR EXPS. 74--45 (ROCKWELL) & 74-53 (MIT)
APPARATUS FOR EXP. 74-36 (GRUMMAN)
ELECTROMAGNETIC LEVITATION FURNACE FOR EXP. 74-48 (G.E.)
MEASUREMENT MODULE
NOSE CONE LENGTH 51.8"
SCIENCE P/L " 114.625
SUB-TOTAL (SCI P/L + NOSE CONE) 166.425"
MSFC-78-PA 4000-476-E

FIGURE 1

Ground-Based Facilities

As an augmentation to the sounding rocket capability, ground-based facilities, namely drop tubes and drop towers, have been developed to provide low cost, functionally flexible, and readily available 0-g test facilities. The Marshall Space Flight Center operates two drop tubes (one of 100-foot length and one of 300-foot length) and a 300-foot drop tower (Figure 2). These facilities provide between two and four seconds of 0-g time. In the drop tubes, molten droplets are released into an evacuated tube and are solidified during the vertical free fall. The drop tower employs a free-falling aerodynamic container within which experiment packages are mounted for 0-g tests.

Aircraft Experiments

By flying parabolic trajectories, short periods of zero gravity can be achieved with aircraft (Figure 3). The NASA/JSC KC-135 has been used for several years to obtain 0-g material science data and equipment verification. This aircraft can accommodate a relatively large experiment package, typically of the SPAR class complexity, which may be either automated or manually operated; the KC-135 0-g operating periods are, typically, 15 to 30 seconds and are quite satisfactory for solidification studies and precursory experiments in other areas, such as containerless processing. More recently, the NASA/DFRC F-104 has been used for MPS precursory experiments. This aircraft accommodates small, automated experiments and can achieve 30 to 60 seconds of microgravity time.

Orbiter Middeck

The Space Shuttle Orbiter middeck area (Figure 4), normally used for crew support functions, may on certain flights be used for accommodation of small experiments. Two accommodation modes are being explored and exploited: (a) use of or replacement of storage lockers and (b) use of the galley rack area. The middeck area is suitable for SPAR type experiment packages that can be operated automatically during 0-g orbital periods or experiments that need access relatively close before launch, for insertion of short shelf-life samples, for example This experiment accommodation will extend the utility of certain of the existing sounding rocket experiments and permit development of relatively low-cost experiments for orbital operations.

Materials Experiment Assembly (MEA)

The MEA project was initiated to provide an early orbital payload capability and to extend the functional life of the sounding rocket experiment devices. The MEA (Figure 5) is a self-contained payload of SPAR type experiments that may be

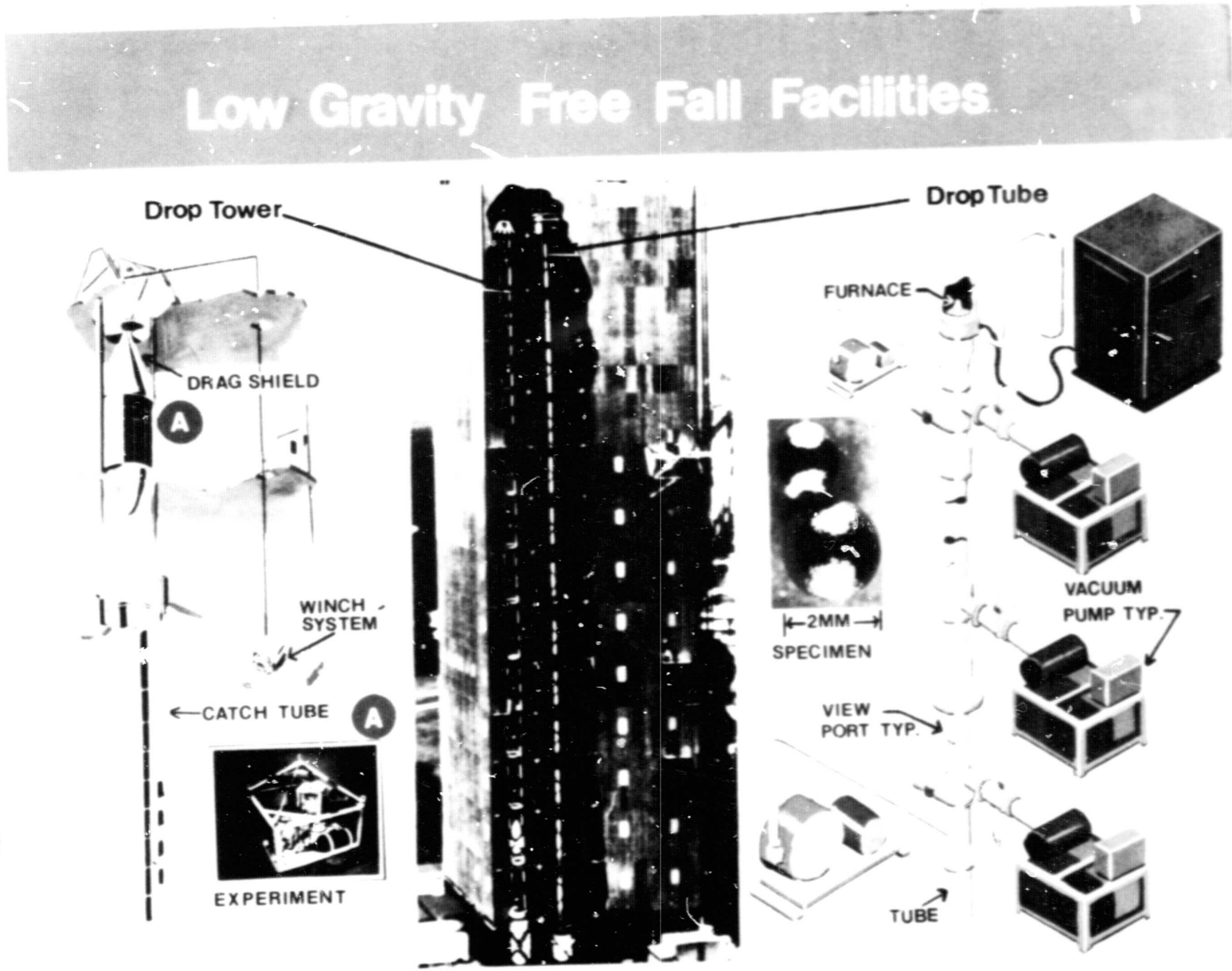

FIGURE 2

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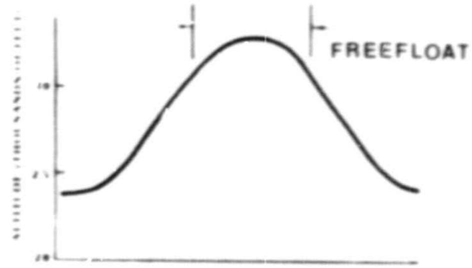
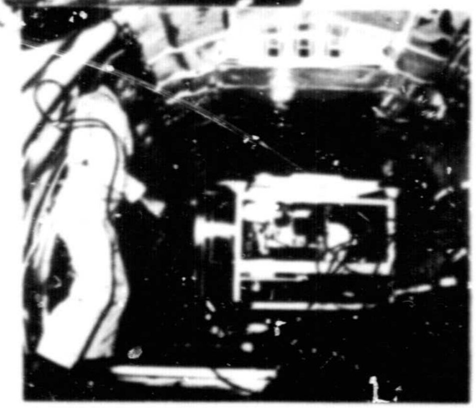
Use Of NASA Aircraft For Microgravity Experiments

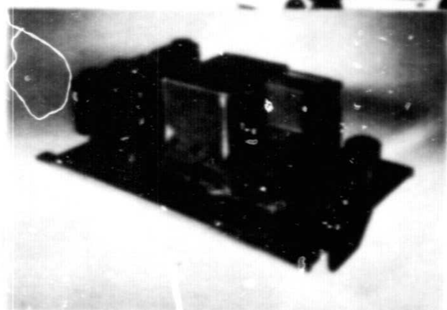


LOW G TIME: <KC-135 15-30 SEC
<F - 104 30-60 SEC

KC-135



CREW IN 0-g



EXPERIMENT PACKAGE

F-104

FIGURE 3

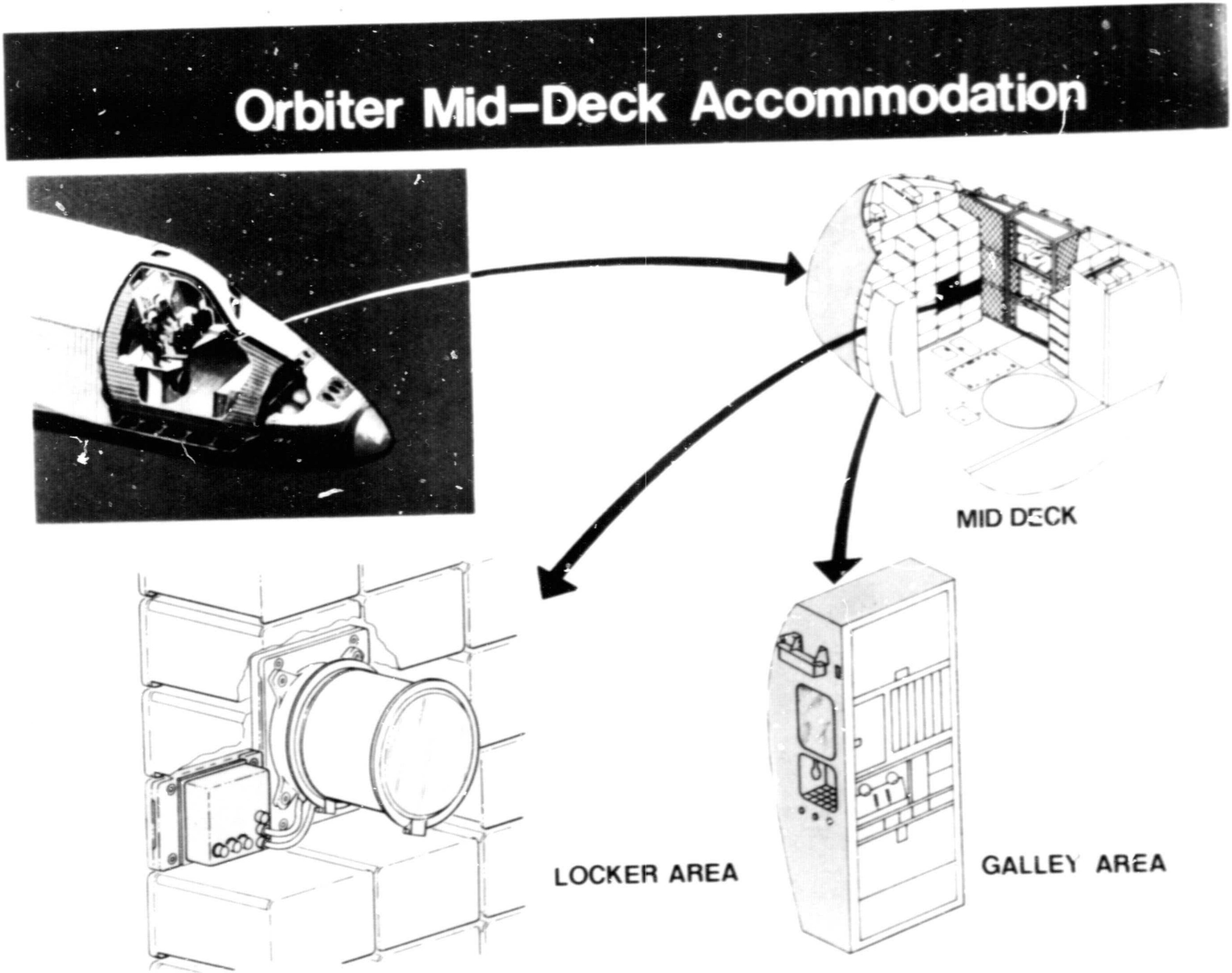
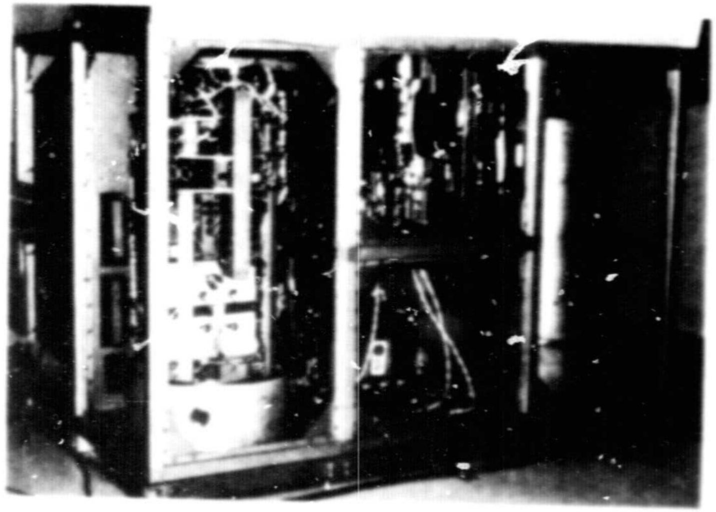
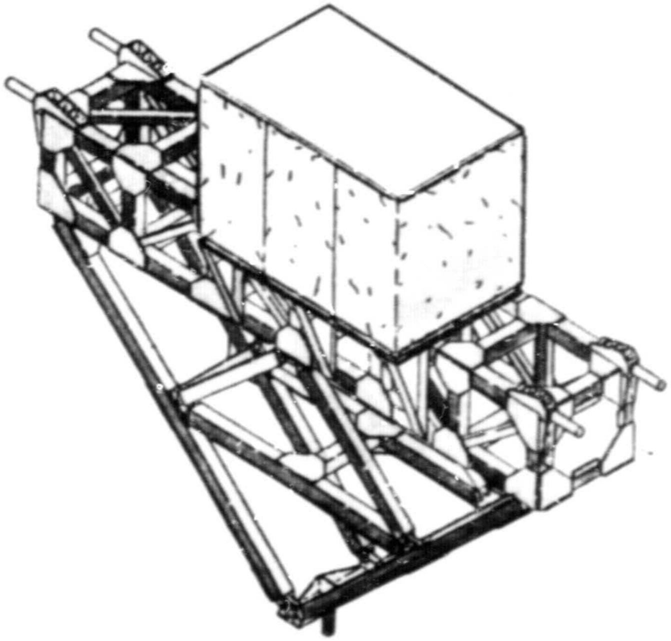

Orbiter Mid-Deck Accommodation
MID DECK
LOCKER AREA
GALLEY AREA

FIGURE 4

MATERIALS EXPERIMENTS ASSEMBLY [MEA]



MEA ON MPE SUPPORT STRUCTURE



MEA ON PALLET

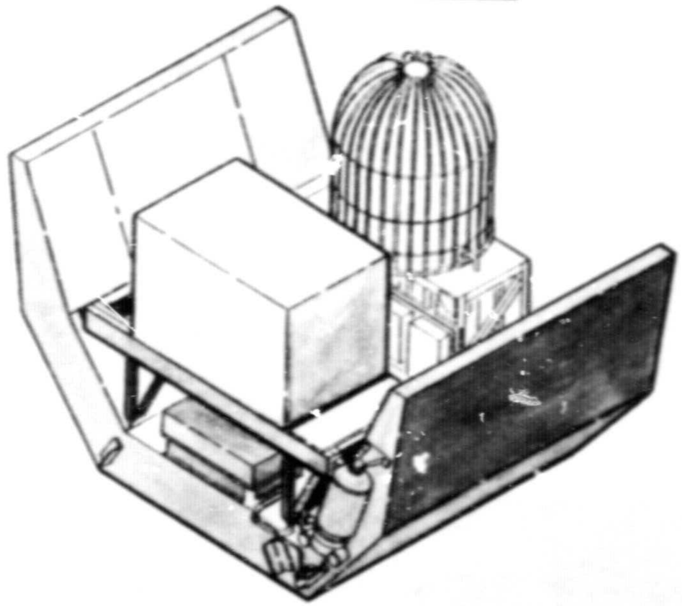


FIGURE 5

flown on the Space Shuttle on missions of opportunity due to the minimal interface requirements. Many investigators have experiments that have matured, through ground-based research and sounding rocket flights, to the point where significantly longer microgravity processing times are imperative for pursuit of the experimental objectives; the MEA will accommodate those reflight investigations on early Shuttle flights, and will provide another valuable step in the learning process towards optimization of low-cost hardware design and integration.

Space Shuttle/Spacelab MPS Planning

There has been considerable emphasis in the past on investigating processes in the early suborbital and orbital experiments that could rapidly lead to the production of commercially viable products in space. While a number of interesting results were obtained, it became clear that considerably more research was required before commercial space processing could become a reality. Careful experiment design was required to take advantage of the space environment and to avoid some of the more subtle problems that are often masked by gravity-driven convection. Much greater attention had to be given to phenomena such as constitutional supercooling and interfacial breakdown; interaction of the solidification front with second phase components; bubble production and removal; and flows produced by surface tension gradients (Marangoni effect), volume change during solidification, and spacecraft motions. It also became clear that much more sophistication was required in process control and diagnostics, particularly with regard to the control and measurement of thermal gradients and quenching rates required for many of the processes.

Another major difficulty that became apparent in attempting to develop commercial applications for space processing from these initial experiments was the identification of specific products. A number of studies has been carried out on the economic benefits of manufacturing specific items such as silicon ribbon, improved turbine blades, and various pharmaceuticals in space. Although such studies had value for creating interest, stimulating ideas, and developing concepts, it was tacitly assumed that space processing would result in a superior product and that improvements in Earth-based technology were limited irrevocably by gravitational effects. As it turns out, many of the desired improvements in commercial products have already been achieved by alternative Earth-based techniques. In other cases, new technology has supplanted the need for the product. This will always be a problem with trying to identify specific needs 10 to 20 years hence.

For these reasons, the present philosophy underlying the MPS program places the highest priority on researching and demonstrating the utility of the space environment for materials science and engineering. Such demonstrations should stimulate researchers and commercial users to work with NASA on a cooperative basis in order to gain access to the space environment for their own purposes. Ultimately, it is expected that privately funded commercial utilization of space for materials science and engineering will occur. For reasons discussed previously, it is not possible at this time to predict exactly what products will be produced or how they will be produced. This will be largely determined by the ingenuity of the people doing research on MPS, the imagination of the entrepreneurs, and the laws of economics. It is NASA's challenge to create the proper environment for this to occur by stimulating research on the ground to isolate requirements for flight experiments, by developing flight hardware that is responsive to experimenter needs in control and diagnostics, by providing easy access and multiple flight opportunities for qualified researchers to perform experiments, and by developing satisfactory patent protection and rights to private corporations to insure them a reasonable charce to return commensurate with their financial risk.

The first task is to develop a thorough understanding of the advantages to be gained by processing materials in space and to determine what phenomena are important in controlling low-g processes. It was established in previous experiments that natural convection arising from either thermal, density, or concentration gradients could be adequately suppressed by going to space. Such convective flows are both significant and potentially detrimental because they give rise to nonuniform diffusion boundary layers as well as transient segregation due to temperature and velocity fluctuations during processes such as crystal growth. Indeed it was demonstrated that crystals with fewer defects and with uniform composition both on a microscopic as well as a macroscopic scale could be grown by taking advantage of the quiescent growth conditions in space. There are, however, other nongravitational flows, such as those induced by surface-tension gradients, volume change, or spacecraft (or laboratory) motion, that operate in space as well as on Earth. Such flows are often masked by gravity-driven convection and are therefore difficult to study. Experiments in space provide a means for separating gravity-driven from nongravity-driven flows and studying them separately. This information is fundamental to the design of space experiments and processes. Additionally, many terrestrial processes can be improved or optimized by a better understanding of flows from which better control strategies can be devised.

The ability to handle liquids and melts in a containerless mode offers unique opportunities to perform scientific experiments such as determining thermodynamic properties of chemically active materials at high temperatures, study of solidification of extreme undercooling, preparation of ultrapure samples of materials, and avoidance of container-induced nucleation of difficult-to-prepare amorphous solids such as bulk metallic glasses and a variety of exotic glasses such as the refractory oxide glasses which tend to devitrify because of heterogeneous nucleation.

The elimination of sedimentation and Stokes flow in low gravity allows the study of a number of phenomena that cannot be adequately studied terrestrially, such as: bubble dissolution by chemical fining agents in glass, bubble centering mechanisms in thin glass shells, bubble deformation and motion in a thermal gradient, ripening of precipitates or flocculates, nucleation and growth of immiscible phases, interaction of solidification fronts with bubbles or second phase materials, solidification of composites with large density differences, preparation of phase-separating glasses, multiphase monotectic solidification, etc.

Predicated on materials science and engineering experiment requirements, MPS payloads (Figures 6 and 7) are being developed to provide a comprehensive materials process research capability for the Spacelab module, when manned interaction is imperative, and the Spacelab pallet, for automated, higher power equipment.

<u>Future Flight Requirements</u>

Several of the proposals submitted in response to the first Announcement of Opportunity (AO) had excellent scientific merit but required greater processing capability than could be developed under the time and functional constraints of the early Shuttle and the Spacelab flights. These proposals were partially funded to enable the investigators to develop their ideas more fully and to participate in requirement definition and design studies of new apparatus. In addition, several conceptual ideas have emerged for apparatus that may be required to meet anticipated materials science and engineering needs as the program matures. Several working groups have been assembled consisting of experts in fields such as fluid dynamics, float zone processing, solidification processes, biological separations, electromagnetic acoustic and other containerless processing technologies, and ultrahigh vacuum processing. These working groups assess the current and projected needs for improvements in the technology in question, estimate the probability of meeting these needs by improvements in terrestrial techniques, determine whether there is sufficient scientific justification for developing new space facilities, and define what characteristics and capabilities such facilities should have.

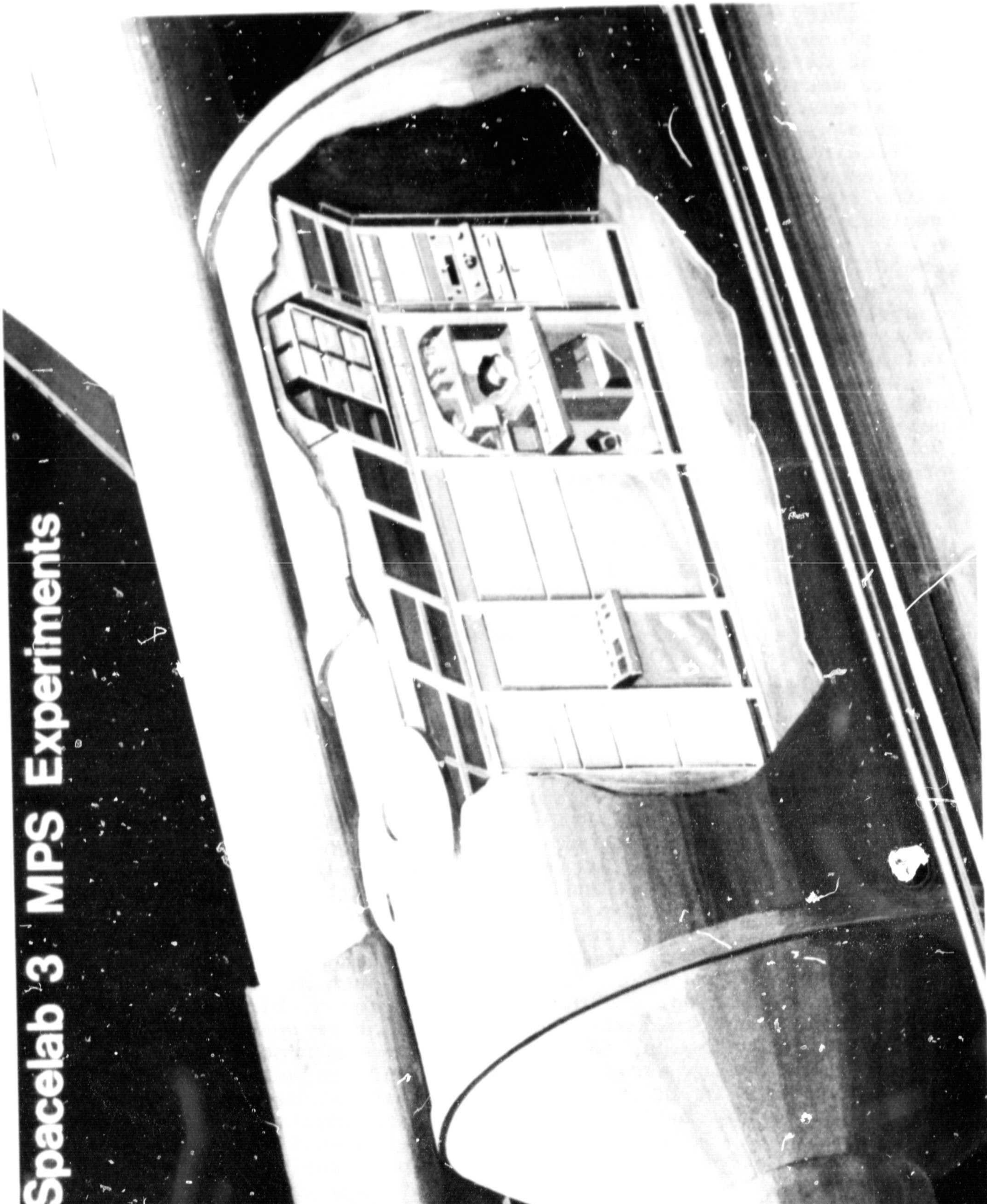


FIGURE 6

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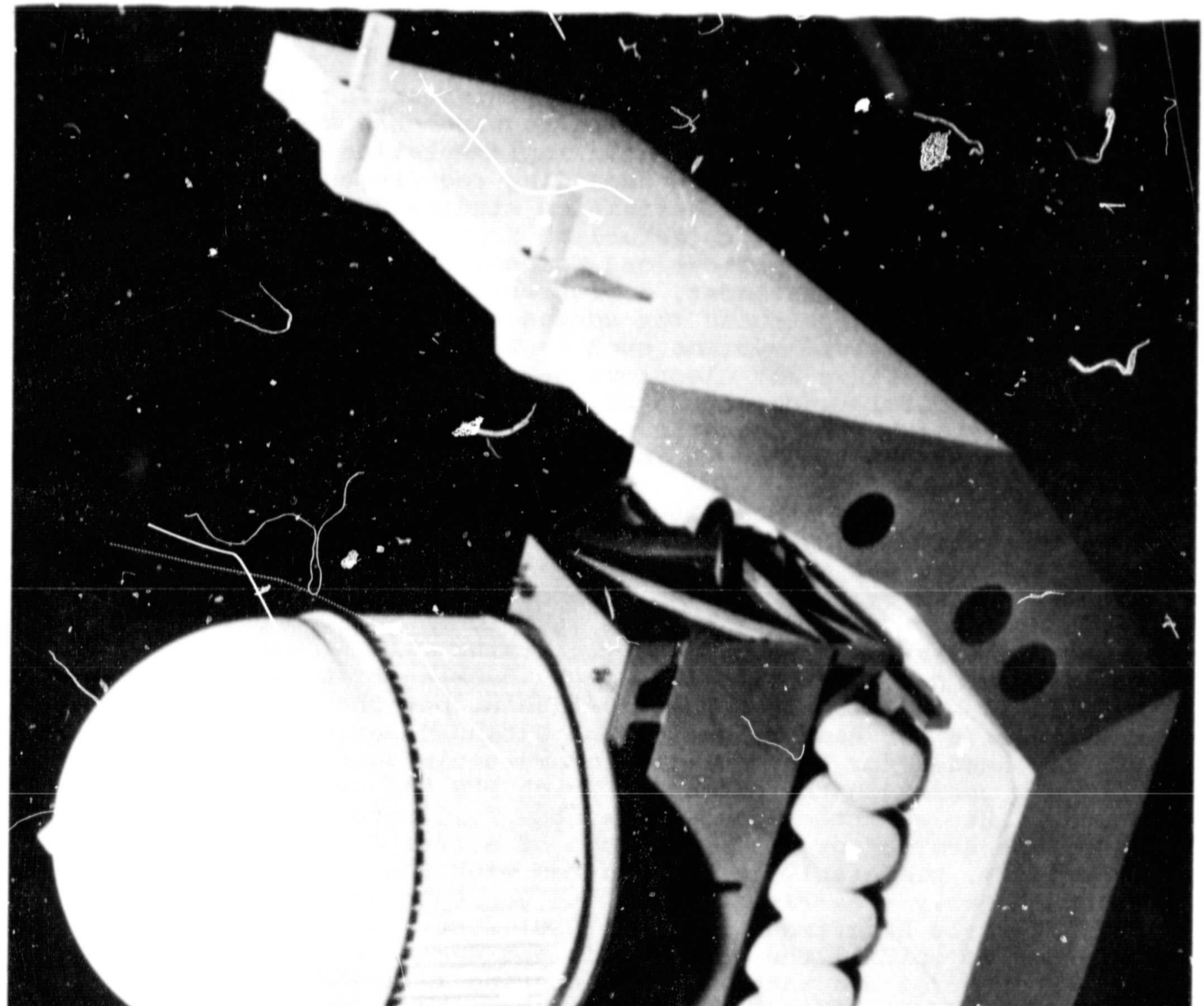

FIGURE 7

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The current investigators and requirements working groups have defined experimental and processing requirements well beyond the technological and programmatic implementation of the development programs. These more demanding requirements are being employed in conceptual and definition studies for advanced processing equipment and to establish Supporting Research and Technology (SRT) and Applications Technology Development (ATD) pursuits. In most instances, a progressive evolution of capability will be necessitated for consonance with experimental maturation in payload systems such as float zone refining, bioprocessing, acoustic and electromagnetic containerless processing, and chemical processing. Some evolutionary steps will be accommodatable on the Space Shuttle, especially in conjunction with the power systems in the docked or sortie operational mode.

The nominal payload capability of the Space Shuttle in terms of power availability (7 kW), energy (50 kW-hrs), heat rejection (8.5 kw), and microgravity stability is of significant benefit for materials process research, but it is severely limiting for processing materials in space. The demands for power and energy can be offset by carrying auxiliary power supplies as part of the payload or by docking to a power system when it is operational in the mid-1980's, but the attendant requirements for heat rejection and extended periods of microgravity needed for long duration or multiple sample processing finitely constrain the extent to which MPS can be accomplished in the Shuttle sortie mode. Thus, the full potential of MPS cannot be evolved or realized short of a free-flying (platform) capability, preferably in conjunction with the power system, although early free-flying satellite concepts are under study. The Materials Experiment Carrier (MEC) free-flying platform is intended to fulfill the early needs for demonstration of process control and materials engineering in space. It has been derived from forecasts that a materials processing capability of 400 to 600 samples per year (with each sample consuming an average of 21 hours of microgravity process time) and 150 kW-hrs of energy must be accommodated for a meaningful, self-sustaining applications program; the MEC, in conjunction with the power system, (Figure 8) will provide the means to achieve such a program. Furthermore, the MEC is designed to provide simple physical and functional interfaces for commercial payloads, and reduce Shuttle transportation costs, both of which are intended to minimize the actual cost per sample.

Some investigators require ultrahigh vacuum environments for ultrapurification of metals, semiconductor and solar cell studies, and for electrotransport investigators; therefore, analyses of the vacuum potentials in the vicinity of spacecraft in near Earth orbit are in progress. The use of a wake shield concept to "sweep" atomic and molecular species from the

MATERIALS EXPERIMENT CARRIER (MEC)

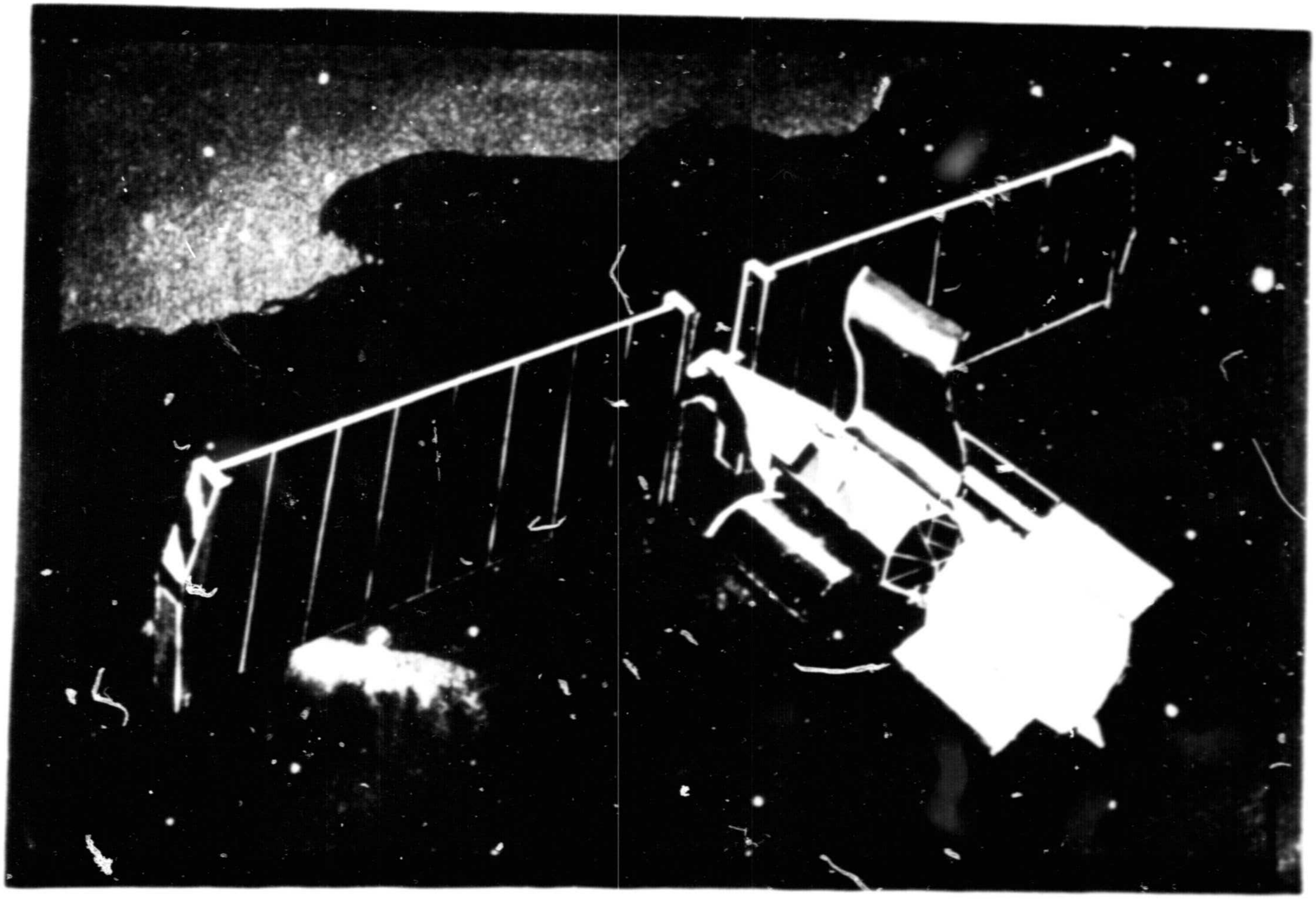


FIGURE 8

orbital path may create a localized environment approaching 10^{-14} torr with nearly infinite pumping capacity. A wake shield demonstration is considered for a Shuttle flight to empirically determine the potentialities of this concept which may lead to experimental techniques for ultrahigh vacuum research on materials processes.

The composite of the experimental payloads, embracing the investigator requirements in the various areas of gravitational and vacuum research, constitutes a national materials research capability for use by scientific and industrial investigators on a routine basis for their specific interests (Figure 9).

As a basis for determining future materials science and engineering requirements, it is intended to initiate AO's on approximately an annual basis for new experiments. This will give investigators, completing their work on development experiments as well as investigators participating in the ground-based program, a periodic chance to enter into flight experimentation when their program requires it. A similar announcement for joint endeavors between NASA and the private sector will be employed to stimulate and effect commercial interest and applicability.

Ground Research Program

Each of the flight programs described previously represents a major commitment on the part of the Principal Investigator (PI) and NASA to an extensive ground-based research program consistent with the advice of a committee of the National Research Council on the Scientific and Technological Aspects of Materials Processing in Space (STAMPS). The obvious study objectives are to develop the experiment protocol, prepare the samples, test the apparatus, and develop the analysis procedures; but, in addition, the PI is expected to explore the best possible techniques that can be employed on the ground to accomplish the experiment objective. For example, in most of the Skylab and ASTP experiment, the flight samples were compared to samples processed under identical conditions on the ground to elucidate the effect of gravity. While this is an excellent control and should certainly be done, it by no means represents the best that can be done on the ground, because the process used was not generally optimized for a one-gravity environment. For example, crystal growth experiments done in space should also be compared to results that can be obtained by using the best techniques for stabilizing against convection, e.g., stabilizing geometries, magnetic fields, etc. Periodic reviews by experts in the field are being conducted to provide constructive criticism of the experiment and to suggest possible improvements. A final science review will be held before the experiment is committed to flight to determine the adequacy of preparation.

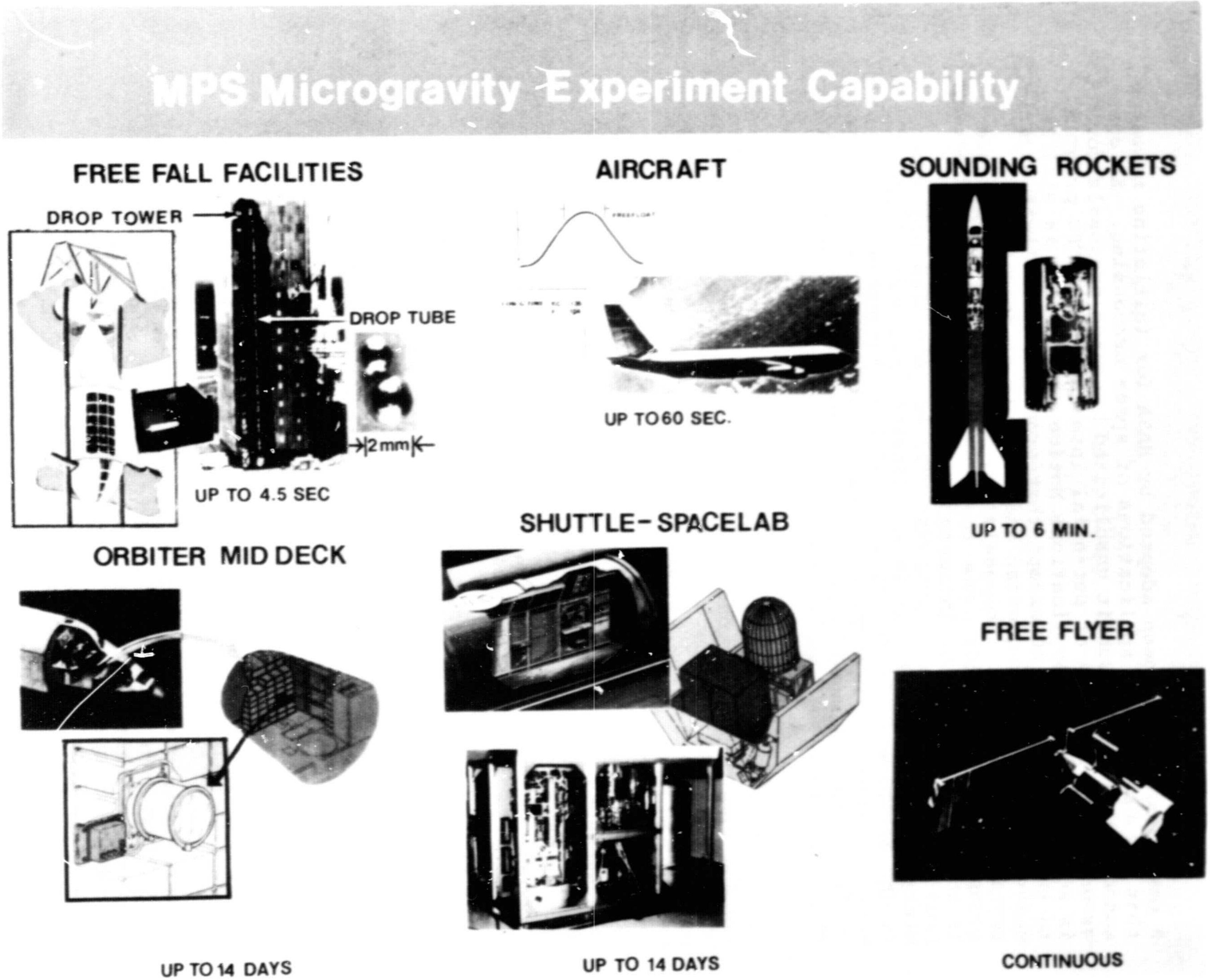

MPS Microgravity Experiment Capability
FREE FALL FACILITIES
DROP TOWER
DROP TUBE
2 mm
UP TO 4.5 SEC
AIRCRAFT
UP TO 60 SEC.
SOUNDING ROCKETS
UP TO 6 MIN.
ORBITER MID DECK
UP TO 14 DAYS
SHUTTLE-SPACELAB
UP TO 14 DAYS
FREE FLYER
CONTINUOUS

FIGURE 9

A new procedure has been adopted by NASA for initiating research that may broaden the applications of space processing. An open-ended invitation to submit unsolicited research proposals for ground-based research of potential interest to the MPS program is advertised by an Applications Notice (AN). This is similar to the more familiar AO except that proposals for flight experiments are not being requested and there is no deadline for receipt of proposals. Proposals are peer reviewed, and those accepted are funded for a one- to three-year development program. If the research results indicate that a flight program is required and feasible, a proposal will be generated and submitted to the next AO. It is anticipated that most of the flight experiments in future years will be generated through this procedure. The complete listing of experiments selected to date through the AO process is provided in Figures 10 (SPAR/MEA), 11 (Spacelab), and 12 (Molecular Wake Shield).

In addition to developing good research to be carried out in space, it is also recognized that it is essential to develop new and sophisticated techniques for carrying out the experiments. For this purpose, an ATD program has been initiated to fund the definition and development of new hardware and facilities up to a "brass board" model. Included in such effort is developing and adapting state-of-the-art technology to specific problems in the MPS program, such as: high temperature heat pipe furnaces with precise thermal control; new measurement techniques such as localized fringe holography, laser doppler velocimetry, and high resolution thermal imaging systems; improved techniques for heating and quenching samples; new containerless position control techniques, automation and on-orbit servicing, and extension of the technologies to extra-terrestrial materials processing.

Commercialization

The ultimate goal of the MPS program is to develop a viable commercial interest in using space to: (1) perform 0-g research to improve industrial technology or to develop new products on Earth, (2) to prepare research quantities of material in 0-g to serve as paradigms with which to compare current Earth-based technologies and, if viable, (3) to produce specific materials in space of sufficient quantity and value to stand on their own economically.

It is recognized that it will be necessary for NASA to go more than halfway toward demonstrating to potential industrial users that they can learn more about their process by conducting experiments in space as well as do things in space that they cannot do on Earth. This can best be accomplished by working closely with industries to the point of understanding their

SPAR EXPERIMENTS INVENTORY

AO-74-1
NOVEMBER 8, 1974
FLIGHT EXPERIMENTS

EXP. NO.	EXP. TITLE	PI	ORGANIZATION
74-5 *	SPACE SOLIDIFICATION OF Pb/Sb EUTECTIC	PROF. R. POND	MARVALAUD, INC.
74-10 *	FEASIBILITY OF PRODUCING CLOSED CELL METALS FORMS	DR. J. PATTEN	BATTELLE-NORTHWEST
74-15 *	UNIFORM DISPERSIONS OF CRYSTALLIZATION PROCESSING	PROF. D. UHLMANN	MIT
74-18 *	CHARACTERIZATION OF ROCKET ENVIRONMENT	MR. C. SCHAFER	NASA/MSFC
74-21	DENDRITE REMELTING AND MACROSEGREGATION	DR. M. JOHNSTON	NASA/MSFC
74-30	AGGLOMERATION IN IMMISCIBLE FLUIDS	DR. S. GELLES	GELLES ASSOCIATES
74-34 *	CASTING THORIA DISPERSION - STRENGTHENED COMPOSITES AT LOW-G	DR. L. RAYMOND	AEROSPACE CORP.
74-36 *	INTERACTION OF BUBBLES WITH SOLIDIFICATION INTERFACES	DR. J. PAPAZIAN	GRUMMAN AEROSPACE
74-37 *	CONTAINED POLYCRYSTALLINE SOLIDIFICATION	DR. J. PAPAZIAN	GRUMMAN AEROSPACE
74-42	GLASS FORMATION	MR. R. HAPPE	ROCKWELL INTER.
74-45 *	EPITAXIAL GROWTH OF SINGLE CRYSTAL FILMS	DR. D. LIND	ROCKWELL INTER.
74-48 *	BERYLLIUM GRAIN REFINEMENT	DR. G. WOUCH	GE SPACE SCIENCES
74-49 *	AMORPHOUS FERROMAGNETS	DR. A. LORD	DREXEL UNIVERSITY
74-53 *	VISCOUS COALESCENCE	PROF. D. UHLMANN	MIT
74-62 *	AGGLOMERATION OF IMMISCIBLES	PROF. H. AHLBORN	UNIV. OF HAMBURG
74-63 *	PREPARATION OF SPECIAL ALLOY UNDER ZERO-G FOR MAGNETIC HARD SUPERCONDUCTORS	DR. HEYE	TECHNICAL UNIV. OF WEST GERMANY

* COMPLETED

FIGURE 10

SPAR EXPERIMENTS INVENTORY

AO-74-1
NOVEMBER 8, 1974
STUDY EXPERIMENTS

EXP. NO.	EXP. TITLE	PI	ORGANIZATION
74-9 *	PARTICLE ELECTROPHORESIS TESTING IN ROCKET FLIGHT	DR. P. TODD	PENNSYLVANIA STATE
74-14 *	SPIDER CELL ELECTROPHORESIS AT ZERO GRAVITY	DR. M. BIER	UNIV. OF ARIZONA
74-24 *	DIFFUSION COEFFICIENT OF $GeO \cdot K_2O$ GLASS	MR. R. NICHOLS	NASA/MSFC
74-33 *	THERMODYNAMIC PROPERTY DETERMINATION IN LOW GRAVITY	DR. J. MARGRAVE	RICE UNIVERSITY
74-43 *	ELECTROPHORESIS EQUIPMENT DESIGN FOR SPACE	DR. D. BROOKS	BECKMAN INSTRUMENTS

* COMPLETED

SPAR EXPERIMENTS

AO 76-02
FEBRUARY 6, 1976

FLIGHT EXPERIMENTS

EXP. NO.	EXP. TITLE	PI	ORGANIZATION
76-19 *	CHARGED WATER-DROP OSCILLATIONS	DR. C. SAUNDERS	UNIV. OF WYOMING
76-20	CONTAINERLESS PROCESSING TECHNOLOGY	DR. T. WANG	JPL
76-22	DIRECTIONAL SOLIDIFICATION OF MAGNETIC COMPOSITES	DR. D. LARSON	GRUMMAN AEROSPACE
76-36	COMPARATIVE ALLOY SOLIDIFICATION	DR. M. JOHNSTON	NASA/MSFC
76-39	DENDRITE SOLIDIFICATION AT SMALL SUPER-COOLING	DR. M. GLICKSMAN	RENSSELAER POLY-TECHNIC INSTITUTE
76-51	MONOTECTIC AND HYPERMONOTECTIC SOLIDIFICATION EXPERIMENT	DR. C. POTARD	NUCLEAR RESEARCH GRENOBLE, FRANCE
	STUDY EXPERIMENTS		
76-5 *	MARAGONI CONVECTION (WITHDRAWN BY PI)	MR. S. HARDY	NBS
76-13 *	LIQUID SHAPING AND FORMING (WITHDRAWN)	MR. R. WHYMARK	INTERSONICS, INC.
76-26 *	GLASS FINING IN LOW-G (COMBINED WITH 76-35)	DR. W. WILCOX	CLARKSON COLLEGE
76-35 *	GLASS FINING	DR. H. SMITH	WESTINGHOUSE, CORP.
76-30 *	COUNTER CURRENT DISTRIBUTION OF BIOLOGICALS	DR. D. BROOKS	BECKMAN INSTRUMENTS
76-43 *	PREPARATIONS OF MONODISPERSED LATEXES (WITHDRAWN BY PI)	DR. J. VANDERHOFF	LEHIGH UNIVERSITY
76-44 *	ELECTROCHEMISTRY IN LOW-G	DR. P. GRODZKA	LOCKHEED MISSILES & SPACE CO., INC.

* COMPLETED

SPAR EXPERIMENTS

AO-77-4
JUNE 3, 1977

FLIGHT EXPERIMENTS

EXP. NO.	EXP. TITLE	PI	ORGANIZATION
77-9	FOAM COPPER	PROF. POND	MARVALAUD, INC.
77-13	GLASS FINING EXPERIMENT IN LOW-G	DR. W. WILCOX	CLARKSON COLLEGE
77-18	DYNAMICS OF LIQUID BUBBLES	DR. T. WANG	JPL
77-E	ELECTROPHORESIS	DR. G. SEAMAN DR. D. SAVILLE DR. A. JOHNSON	UNIV. OF OREGON PRINCETON UNIV. N.Y. MEDICAL CENTER

STUDY EXPERIMENTS

77-6*	FLUID MIXING EFFECTS IN LEVITATED MELT	MR. C. SCHAFER	NASA/MSFC
77-7*	LIQUID METAL DIFFUSION IN SOLUBILITY GAP MATERIALS	PROF. R. POND	MARVALAUD, INC.

MEA PRINCIPAL INVESTIGATORS

PI/INSTITUTION	EXPERIMENT TITLE
*DR. WAGNER/ARIZONA STATE UNIVERSITY (WITHDRAWN BY PI)	SOLID ELECTROLYTES CONTAINING DISPERSED PARTICLES
DR. GELLES/S. H. GELLES ASSOCIATES	LIQUID MISCIBILITY GAP MATERIALS
DR. WIEDEMEIER/RPI	VAPOR GROWTH OF ALLOY-TYPE SEMICONDUCTOR CRYSTALS
MR. HAPPE/ROCKWELL INTERNATIONAL	CONTAINERLESS PREPARATION OF ADVANCED OPTICAL GLASSES

ORBITER MIDDECK PRINCIPAL INVESTIGATORS

DR. VANDERHOFF/LEHIGH UNIVERSITY	LARGE-PARTICLE-SIZE MONODISPERSE LATEXES

* COMPLETED

SPACELAB 3 PRINCIPAL INVESTIGATORS

PI/INSTITUTION	EXPERIMENT TITLE
MR. SCHNEPPLE/EG&G	HgI_2 CRYSTAL GROWTH FOR NUCLEAR DETECTORS
DR. LAL/ALA. A&M UNIVERSITY	SOLUTION GROWTH OF CRYSTALS IN ZERO GRAVITY

SPACELAB PALLET MPS-1 PRINCIPAL INVESTIGATORS

PI/INSTITUTION	EXPERIMENT TITLE
DR. GELLES/S. H. GELLES ASSOCIATES	LIQUID MISCIBILITY GAP MATERIALS
DR. LEHOCZKY/MDAC	GROWTH OF SOLID SOLUTION CRYSTALS
DR. LARSON/GRUMMAN AEROSPACE	ALIGNED MAGNETIC COMPOSITES
DR. WIEDEMEIER/RPI	VAPOR GROWTH OF ALLOY-TYPE SEMICONDUCTOR CRYSTALS
DR. CROUCH/LARC	SEMICONDUCTOR MATERIALS GROWTH IN LOW G ENVIRONMENT

FIGURE 11

SHUTTLE EXPERIMENTS SELECTED THROUGH THE AO PROCESS BUT CURRENTLY PART OF GROUND-BASED RESEARCH PROGRAM

PI/INSTITUTION	EXPERIMENT TITLE
DR. FOWLE/A. D. LITTLE	INVESTIGATION OF MARAGONI EFFECT IN CRYSTAL PROCESSING
DR. BIER/UNIVERSITY OF ARIZONA	HORMONE PURIFICATION BY ISOELECTRIC CELLS
DR. VAN OSS/SUNY	ELECTROPHORESIS OF HUMAN PANCREATIC CELLS
DR. OSTRACH/CASE WESTERN	SURFACE TENSION DRIVEN CONVECTION PHENOMENA
DR. VERHOEVEN/IOWA STATE UNIVERSITY	FLOAT ZONE EXPERIMENTS IN SPACE
*DR. NYIRI/LEHIGH UNIVERSITY	MULTIPURPOSE SPACE BIOREACTOR SYSTEM
DR. MIESZKUC/JSC	TISSUE CULTURE GROWTH/FERMENTATION
DR. WEINBERG & NEILSON/JPL	INVESTIGATION OF SPACE PRODUCED GLASSES
DR. REMBAUM/JPL	ELECTROPHORETIC CELL SEPARATION BASED ON IMMUNOMICROSPHERES
*MR. SCHAFER/MSFC	FLUID MIXING EFFECTS IN LEVITATED MELTS
DR. LACY/MSFC	NUCLEATION AND GROWTH OF IMMISCIBLE PHASES
DR. JOHNSTON/MSFC	DIRECTIONAL SOLIDIFICATION OF IMMISCIBLE ALLOYS
DR. CHIOVETTI/UAB	WHOLE-CELL ELECTROPHORESIS ABOARD SPACELAB
DR. SUBRAMANIAN/CLARKSON COLLEGE	PHENOMENA IN CONTAINERLESS GLASS PROCESSING
DR. SHLICHTA/JPL	CRYSTAL GROWTH IN A SPACECRAFT ENVIRONMENT

* COMPLETED

MOLECULAR WAKE SHIELD PRINCIPAL INVESTIGATORS

PI/INSTITUTION	EXPERIMENT TITLE
* DR. NEUGEBAUER/GE	ULTRAVACUUM VAPOR EXPITAXIAL GROWTH OF SILICON
* DR. GRUNTHANER/JPL	ULTRAHIGH VACUUM SEMICONDUCTOR THIN FILM TECHNOLOGY
* DR. SCHMIDT/IOWA STATE UNIVERSITY	ELECTROTRANSPORT OF SOLUTES IN REFRACTORY METALS
* DR. SCHMIDT/IOWA STATE UNIVERSITY	EFFICIENT SOLAR CELLS BY SPACE PROCESSING
* DR. BUNSHAH/UCLA	ULTRAPURE METALS PREPARATION IN SPACE

* COMPLETED

FIGURE 12

problems sufficiently to identify areas in which materials science and engineering can best be utilized. It is probably not realistic to expect major commitments from industry alone until we have completed a sequence of spaceflight opportunities and have been given a chance to demonstrate the potential that space offers. Also, ways must be found to select experiments for flight, protect the proprietary rights of the customer, reduce the lead time, and lower the costs of conducting experiments in order to attract the private industrialist.

An important first step will be the establishment of joint endeavors with industrial users to assist them in exploring areas where MPS can be utilized to meet their own needs. In general, these joint endeavors are envisioned to be "constructive partnerships" between NASA and industrial firms wherein the parties are seen as equals who have enough common objectives to make the endeavor worthwhile for both. Also arrangements are being worked out to lease NASA facilities and for cooperative development facilities. Increasing commitment on the part of the user will be required as the project matures.

The Commercial Applications Office, MPS Projects Office, MSFC, has been created to work exclusively with commercial interests. This team forms a bridge between NASA and the commercial community, serving as a source of information and assistance for the user as well as a focal point for commercial views and a channel by which these views can be articulated to NASA. This team is also working to obtain clarification of patent protection rights, proprietary rights, liabilities, leasing policy, and pricing. It is through this effort that NASA believes it can provide a simpler interface to the private sector, develop a better understanding of the incentives needed to elicit private initiatives, and stimulate the inventive genius and entrepreneurial spirit in this country to fully utilize the benefits to be derived from the MPS program.

Predicated upon the current understanding of industrial technical interests and requirements for MPS, definition studies are being pursued on advanced materials processing carriers to accommodate mission duration, utilities, and sample requirements, evolving from a NASA-sponsored technology characterization to industry-sponsored research and commercial application.

<u>Materials Science and the Space Environment</u>

Gravitational forces generally are manifested in materials science and engineering in one or more of the following ways (Figure 13) and are frequently detrimental in the material engineering disciplines depicted in Figure 14:

GRAVITATIONALLY INDUCED PHENOMENA

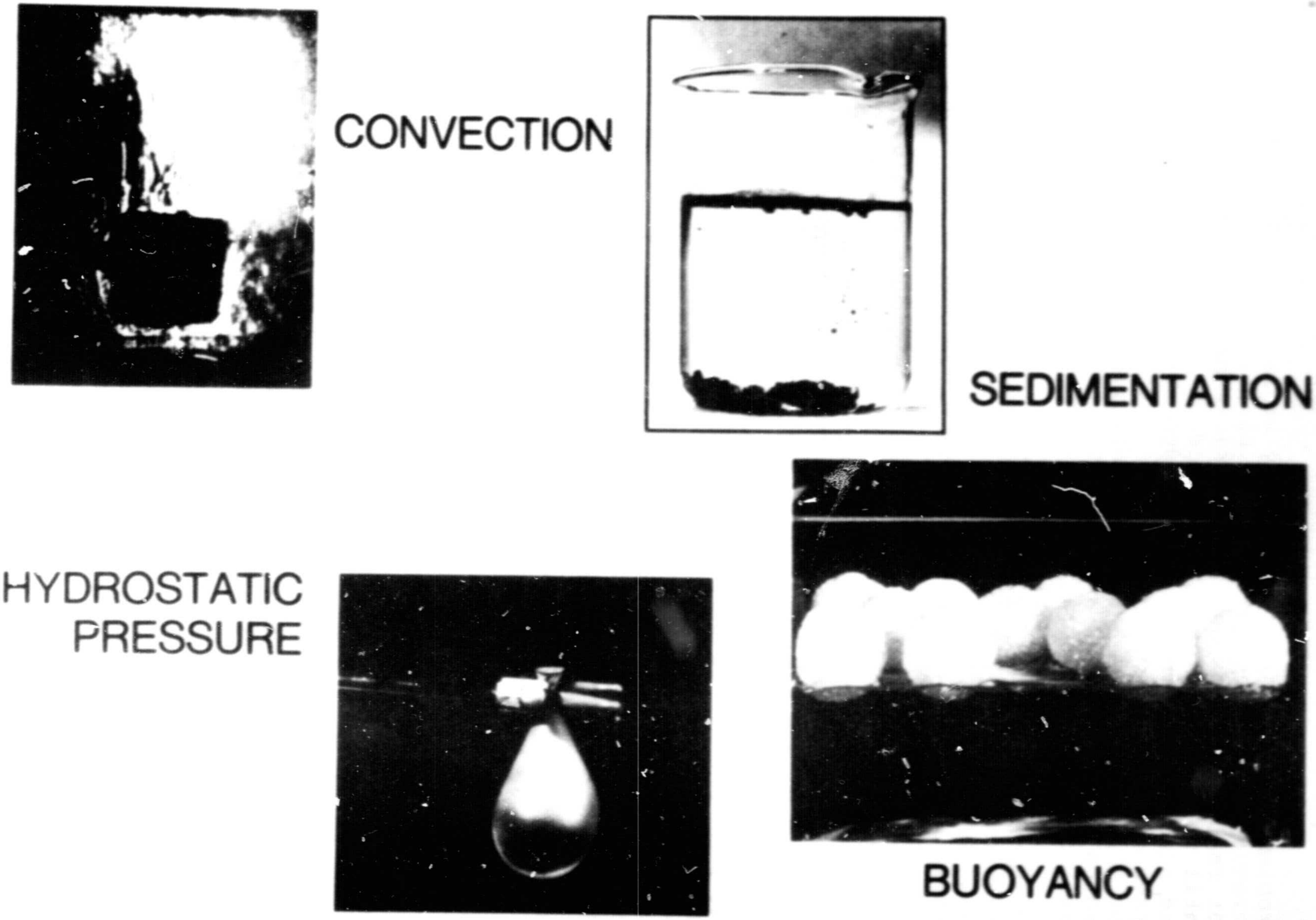


FIGURE 13

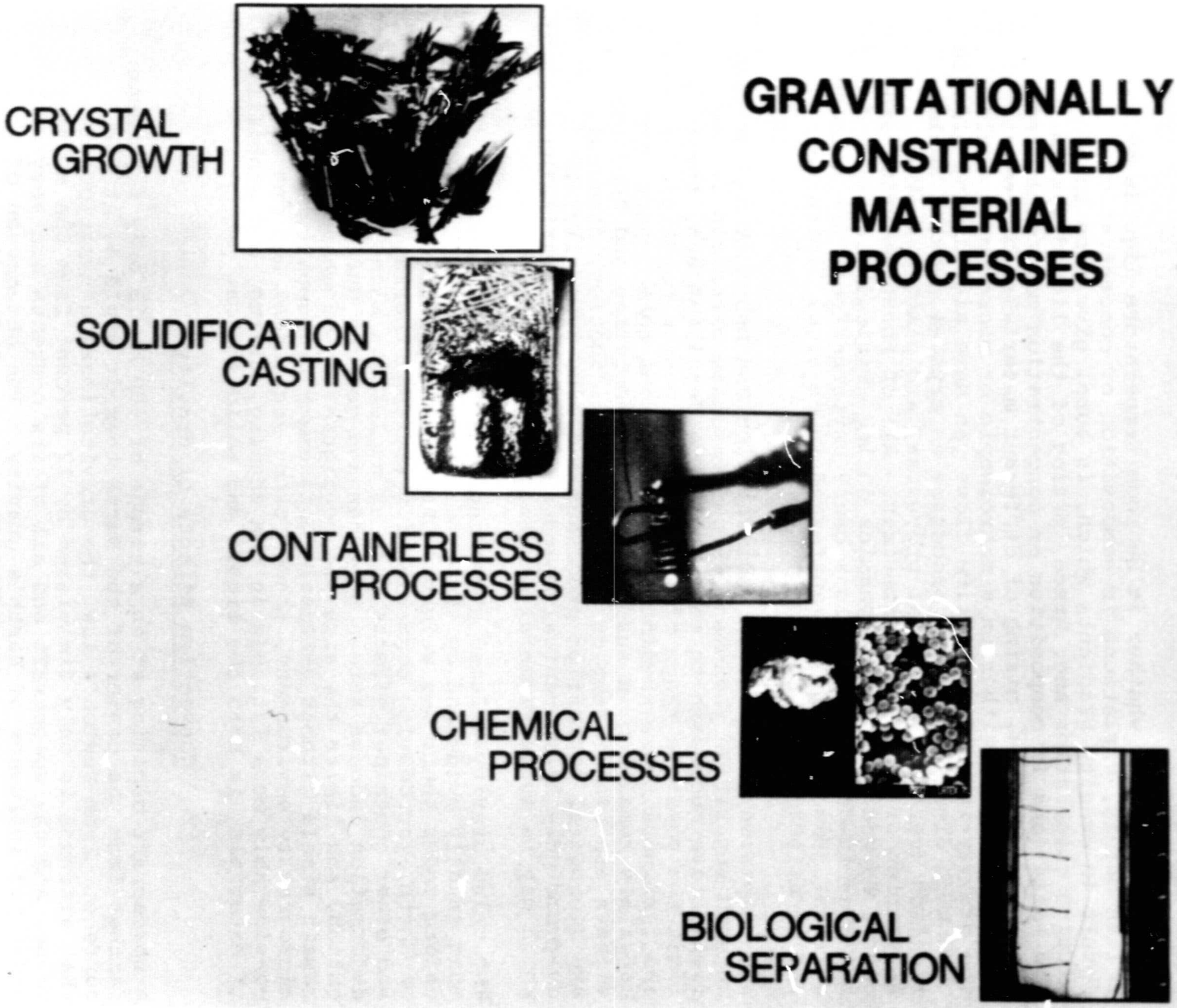

GRAVITATIONALLY
CONSTRAINED
MATERIAL
PROCESSES
CRYSTAL GROWTH
SOLIDIFICATION CASTING
CONTAINERLESS PROCESSES
CHEMICAL PROCESSES
BIOLOGICAL SEPARATION

FIGURE 14

Convection
Sedimentation/Buoyancy
Hydrostatic Pressure (Wall Effects)

In fluid systems, whether it be room temperature liquids or molten metals, variations in composition or concentration result in density gradients which, in turn, give rise to convective circulation and, hence, mixing of the liquid system. The variations in composition or concentration may result from chemical reactions, mixing of different materials, or temperature variations, either on a macroscopic or microscopic scale. The gravity-induced convective flows can have significant effects upon such diverse material processes as crystal growth, solidification (casting), chemical processes, and electrokinetic separation of biological materials. All of these material processes depend upon fluid dynamics during critical phases, and the gravity-driven convections cause perturbations during these critical phases which are manifested in physical limitations and imperfections.

The companion phenomena of sedimentation and buoyancy are gravity-induced separation phenomena which segregate materials in the fluid state according to their relative densities and, thereby, limit the possible range of alloy and composite material systems, and terminate those physiochemical reactions that depend upon materials remaining in suspension. Sedimentation and buoyancy effects are omnipresent on Earth in solidification, chemical, and biological separation processes and can, typically, be overcome only by mechanical means such as vigorous stirring which may be as detrimental as the phenomena themselves.

The third gravity-induced phenomenon, hydrostatic pressure, is most readily evidenced by the tendency of liquids and solids to deform under their own weight. Thus, liquids must be contained on Earth, introducing contamination sources, thermal convection, and other container effects such as nucleation sites. Self-deformation induces strain patterns and defects during solidification, and limits the size and configuration of masses that remain stable without external confinement or support. In a microgravity environment, these forces are absent and one has considerably more latitude in the shaping, mixing, and stability of materials, in both the liquid and solid states.

Convective Effects of Gravity

A spacecraft orbiting at an altitude of 400 km is only 6 percent farther from the center of the Earth than it would be at the surface. From Newton's law, the gravitational attraction at that altitude is only diminished by 12 percent from the surface value, and the spacecraft and all of its contents are very much under the influence of Earth's gravity. The phenomenon of

weightlessness occurs because the spacecraft and its contents are in a state of free fall, and the weightless state is relative only to the reference frame moving with the spacecraft.

A zero-gravity environment is an ideal situation that, in practice, can never be completely realized. There are a number of kinetic effects associated with an actual spacecraft that produce artificial gravity-like forces. Any unconstrained object in a spacecraft is actually in its own orbit around the Earth. Only if this object is located at the center of mass of the spacecraft will it have exactly the same orbit. If the spacecraft is held in an inertial orientation, that is, constant orientation relative to the fixed stars, an object located at some distance from the center of mass will drift to an equal distance on the other side of the spacecraft and back during one orbital revolution. The acceleration associated with this motion, which results from the difference between the orbits of the object in question and the spacecraft, amounts to $10^{-7}g$ (one-ten millionth of the Earth's gravity) for every meter of lateral displacement from the spacecraft center of mass.

The residual atmosphere even at orbital altitude exerts a slight drag force on the spacecraft and causes a small deceleration. A free object inside the spacecraft is not subjected to this force and, therefore, has an apparent acceleration relative to the spacecraft. At 400 km altitude, the force imparted to a spacecraft from this drag is .001 Newton per square meter, which is only a hundred millionth of the atmospheric pressure at the Earth's surface. This atmospheric drag results in acceleration on the order of 10^{-6} to $10^{-7}g$.

These accelerations represent the quiescent background associated with near-Earth orbital flight. Normal operations within a spacecraft produce additional accelerations of a random nature called g-jitter which are on the order of $10^{-4}g$. For example, an astronaut nodding his head will impart an acceleration of this magnitude to the spacecraft. Accelerations resulting from astronauts moving from one location to another within the cabin are on the order of 10^{-2} to $10^{-4}g$ when they start and stop, depending of course on the inertia of the spacecraft and how hard they push off and stop. All of these extraneous accelerations must be considered in planning for space processing operations in space. For example, if an object is to be suspended in a furnace for containerless processing, there must be some force applied to it to counteract the residual accelerations and prevent its impact with the furnace wall.

Because of gravitational effects, convective flow results in virtually every Earth-based process involving fluids in which there are horizontal thermal gradients, i.e., temperature differences between two adjacent elements of fluid. Because practically all fluids expand when heated, even the slightest

temperature difference will cause the warmer element to become less dense (or more dense in the few cases such as water below 4°C where the fluid contracts when warmed). In a gravity field, the less dense fluid element will weigh less and will, therefore, be displaced by the heavier fluid. This results in a circulation or convective flow. Systems involving fluids that expand when heated are also unstable against convection if a downward thermal gradient exists; i.e., the bottom is warmer than the top. Flow will result if the gradient exceeds a critical value that depends on the fluid properties and the container size.

Similar convective flow may also be produced by compositional differences. The density of a liquid depends on the amount of dissolved material in it (for example adding salt to water increases its density). Therefore, if there are concentration gradients in the liquid, i.e., if regions exist with different amounts of dissolved material, the different densities will result in buoyancy forces which will drive a convective flow just as in the case of temperature gradients. A graphic example of this can be seen in the schlieren photograph in Figure 15, in which a crystal is being grown by the solution method under 1-g. As the solute is incorporated into the growing crystal, the depleted solvent becomes lighter and rises in a plume above the crystal.

Convective flow is not necessarily undesirable. In many processes, it is used to advantage to produce needed mixing or homogenization. It does, however, often complicate the process and makes it difficult (if not impossible) to predict accurately and control precisely the process parameters (Figures 16 and 17). The weightless environment effectively eliminates the driving force for convective flows in molten metals, liquids, and gases, that arise because of density differences. Diffusion becomes the predominant mechanism for thermal and mass transport. Since diffusion processes can be accurately predicted mathematically, they are subject to much more precise measurement and control. Figure 16 shows the effects of convective mixing in 1-g versus diffusion controlled mixing in 0-g.

Crystal Growth and Solidification: In certain growth processes, such as growth from the melt, it is extremely important to maintain uniform compositional homogeneity at the growth interface and to maintain a very uniform growth rate in order to control the distribution of impurity atoms in the crystal. The impurity atoms (dopants) are intentionally added to produce the desired electrical properties in the crystal. Since only a few parts per billion of impurity can dramatically alter the electrical properties, a microscopically homogeneous distribution of

Crystal Growth Convection Plume

1–g

FIGURE 15

Convective Effects

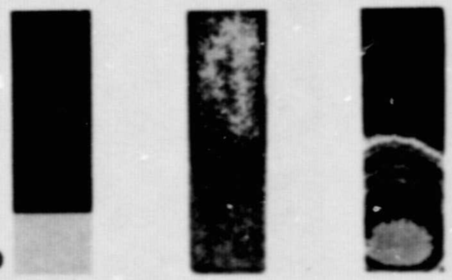
This microphotograph (at 350X) of a surface of a germanium crystal shows compositional striations due to convection in the melt when grown in one gravity. It was taken into space, partially melted and resolidified in low gravity. The more homogeneous composition due to the growth in the absence of convection can be seen.

(350X)

1–g TRANSITION 0–g

The specimen lead shown at the right has a small amount of gold incorporated into one end to demonstrate the diffusion of gold into lead when melted. The micrograph taken of the sample melted in one gravity shows that convective flow has dispensed gold throughout the specimen. The picture taken of the sample melted in low gravity shows gold diffusion progressing through the sample. In microgravity, diffusion controlled processes, undisturbed by convection, are possible.

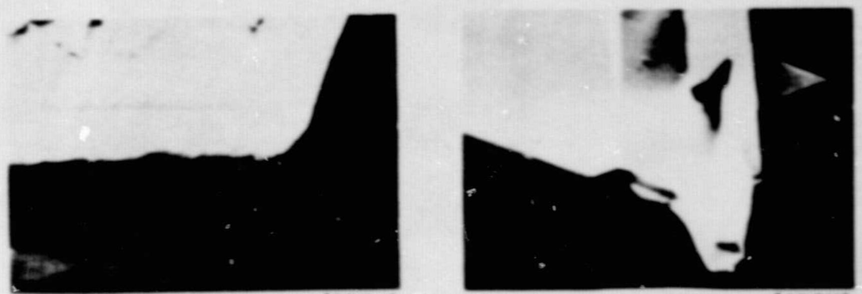
LEAD



0.05% GOLD

PRE–TEST 1–g 0–g

Crystals grown in one gravity often contain defects which effect mechanical and physical properties. Crystals grown in low gravity appear to have fewer dislocations as evidenced by sharper edges. The material shown is germanium-selenium (GeSe).



(400X) (400X)

1–g 0–g

FIGURE 16

Convective Effects

A directionally solidified eutectic composition (natural two-phase solid which grows short fibers) can grow long, continuous fibers in the absence of convection at low gravity. Shown here is a demonstration of this phenomena, using sodium chloride-lithium-fluorine (NaCl-LiF).

1-g 0-g

1-g 0-g

In one gravity, convection causes the hot products of combustion to rise and new reactants to be supplied to the flame. In low gravity, a thin layer of flame can be initiated at the surface of the fuel where it contacts the oxidizer and can be carefully controlled, thus providing a unique opportunity to study combustion phenomena.

1-g

0-g

FIGURE 17

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dopant atoms is extremely important for applications in which it is necessary to have uniform electrical properties over a large area. Such applications include very large scale integrated circuits such as microcomputers, imaging arrays, and image processing arrays which combine the process computer into the same chip that contains the imaging array.

A great deal of effort in crystal growth has gone into trying to understand and control convective effects in such systems. Geometries designed to minimize convective effects are used, and in some cases high magnetic fields have been employed to effectively increase the viscosity of the melt. However, it is not always possible to maintain the degree of control desired for many applications. Unavoidable radial thermal gradients produce stirring of the melt at the growth interface producing compositional variations.

Thermal oscillations, believed to be caused by convective flow in the melt, produce growth rate fluctuations resulting in alternating layers of excessive and deficient dopants levels called striations (Figure 16). The growth of such crystals in space should provide additional insight into the cause of such growth oscillations and could result in greatly improved dopant homogeneity.

The ability to operate at very slow growth rates (R) without fluctuations and the lack of convective mixing in the melt opens the possibility of investigating processes at very high ratios of thermal gradient to growth rate (G/R). These parameters are important in the control of the microstructure of alloy systems and in the control of the growth interface of many crystal systems grown from the melt. There are a number of important solid solution systems such as Hg-Cd-Te, Pb-Sn-Te, Ge-Si, etc. that have not been grown from the melt because the G/R ratio required to maintain a stable interface was beyond the capability of Earth processes. The ability to produce such materials in bulk quantities would be a significant breakthrough in developing starting materials for infrared detector and other device fabrication.

The ability to extend the range of R and G/R and to maintain a diffusion controlled environment is important to fundamental studies of solidification phenomena including interface stability, the transition from planar to cellular growth, dendrite formation and growth, lamellar and rod structure in the case of eutectic alloys, and defect formation. The lack of gravity-driven convection again simplifies the situation and allows an idealized theoretical process to be approached. Once the fundamentals of a process are well in hand, the perturbations caused by convective flow in Earth process are easier to

understand and deal with. Also, there is always the possibility that such fundamental studies will uncover a unique microstructure with useful properties.

Another crystal growth process that may benefit from the absence of gravity-driven convection is growth from the vapor. This can be accomplished by either condensation from a supersaturated vapor or by a chemical process in which a transport gas chemically reacts with the source material and is caused to reversibly react at the growth site. In this reverse reaction, the desired atom is deposited on the growing crystal and the transport atom or molecule is released to repeat the process. The latter process has an advantage for materials with very low vapor pressures and/or high melting points because the process does not require extreme temperatures.

The absence of gravity-driven convection should eliminate unwanted fluctuations in composition, temperature and flow at the growing crystal. Since the growth rate is quite sensitive to these parameters, microfluctuations in the growth environment can introduce irregularities in the growing crystal. These structural or chemical defects degrade the electrical and optical performance of the crystal by acting as traps for charge carriers or as scattering or absorption centers.

Electrokinetic Separation: Electrophoresis is an electrokinetic separation process which is based on discrete differences in the net charge on the particles to be separated. An applied electric field causes an ionic current to flow in the buffer solution and interacts with the charged particle and a sheath of opposite-charged ions in the buffer solution to produce a force. The particle moves with a velocity such that the electric force is balanced by the viscous drag in the buffer. This velocity for a given applied field is called the mobility of the particle. Since the charge produced on the particle by the buffer depends on the surface molecules, particles with different surfaces such as different cell types should exhibit unique differences in mobilities and therefore be separable by this process.

There are several variants of electrophoresis that deserve mention. Isotachophoresis "sandwiches" the material to be separated along with appropriate spacer buffers between a leading and trailing buffer. The buffers are chosen such that the anion mobilities are progressively less going from the leading buffer, first material to be separated, first spacer buffer, second material to be separated, second spacer buffer, etc., until the trailing buffer. When the electric field is applied, the system separates into zones of equal mobility. These zones move at constant velocity and have self-sharpening boundaries.

Another variant, known as isoelectric focusing, takes advantage of the fact that the mobility of the particle varies as a function of the pH of the buffer. In fact there is a value of pH, called the isoelectric point, at which the mobility of a particle reverses sign. A special buffer is used which, when subjected to an electric field, establishes a pH gradient. Particles to be separated are driven to their isoelectric points where they are continually focused or concentrated by the pH gradient as shown in Figure 18.

All of these electrokinetic separation processes are easily upset by any convective flow. Electrophoresis is usually carried out using a porous medium such as paper or a gel which allows molecules to migrate but suppresses any convective flow. This is presently one of the most powerful tools available for analytical separation of proteins where only nanogram to microgram quantities are required. However, it has not been successfully scaled up to separate proteins on a preparative scale where milligrams to kilograms are required. Also, gel electrophoresis is not applicable to cells because of the small pore size of the stabilizing medium.

The most promising method for using any of the electrokinetic separation methods for preparative scale applications is the continuous flow technique. In continuous flow electrophoresis, the sample and the buffer are introduced into a separation chamber shown in Figure 18. A transverse field is applied causing the sample components to spread according to their mobility and the separated sample plus buffer are collected by a series of sample tubes at the bottom of the chamber.

Such devices have been used for a number of years, but the gravity-driven convection imposes severe limitations on their performance. The current flow in the buffer produces heat which must be dissipated through the walls. Therefore, the flow chamber must be made very thin, generally less than a millimeter, to minimize the temperature rise and to prevent unstable convection caused by temperature inversions. Even so, there must exist horizontal temperature gradients due to the heat transfer to the wall. In order to prevent convective circulation from this effect, it is necessary to limit the applied field to reduce the heating and employ sufficient flow velocity to maintain a unidirectional flow. This limits the degree of separation that can be obtained. Also, the restriction on the thickness of the chamber limits the size of the sample stream and intensifies the distortions due to the wall effects. By operating a much thicker chamber in a weightless environment, it should be possible to increase both the resolution and throughput of continuous flow electrophoresis.

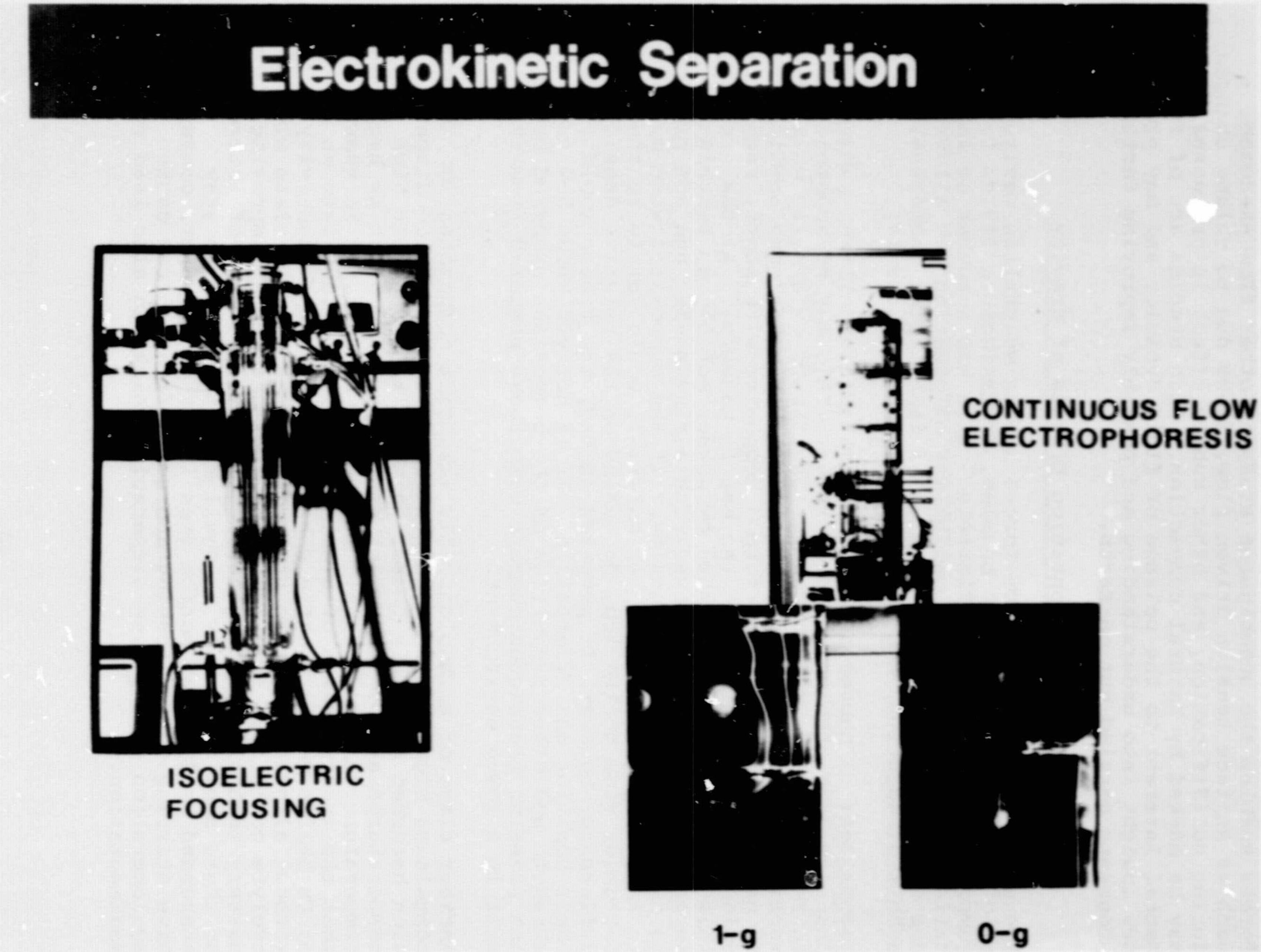
Electrokinetic Separation
ISOELECTRIC
FOCUSING
CONTINUOUS FLOW
ELECTROPHORESIS
1-g
0-g

FIGURE 18

Fluid Mechanics: The absence of buoyancy-driven convective forces enables the unambiguous study of other flow phenomena such as surface tension driven flow, flows due to volume changes during solidification, and other subtle effect in processes that may be masked by natural convection. Such studies are of fundamental interest to the science of fluid dynamics and may provide new insight into understanding and possibly improving certain processes carried out on Earth.

Buoyancy and Sedimentation Effects of Gravity

The elimination of buoyancy forces in the weightless environment also allows particles, gas bubbles, or immiscible fluids to remain in suspension indefinitely. This has a number of implications ranging from the possibility of creating new alloys and composites to fundamental studies of interfacial phenomena, bubble dissolution, and colloidal systems (Figure 19).

Composites: A number of composite materials utilize a dispersed phase to give them unique properties. This may be accomplished on Earth, for example, by supporting fibers externally while a matrix material is solidified around them. For some applications, it is desirable to form a composite with short, randomly oriented fibers throughout the matrix material. At the present, this can only be accomplished by powder metallurgy techniques in which the fibers are mixed with a fine powder and hot pressed to near the theoretical density. If the composites were melted in Earth's gravity, the fiber materials would settle to the bottom or rise to the top, depending on the relative density difference; however, if prepared in 0-g, the fibers would retain their position and orientation. It is not yet known how the strength and other properties of the composites prepared by the hot pressing techniques compare with those prepared from the melt in a low-g environment.

Another class of technologically important composites is those containing microscopic oxide particles, such as oxide dispersion hardened materials that retain their strength at high temperatures, and is important for applications such as high temperature turbine blades. In another example, it is known that the incorporation of alumina (aluminum oxide) into an Ag or Cu halide matrix greatly enhances the ionic conductivity without allowing electron transport. Such a solid state electrolyte could have some important applications in improving battery technology. In general, the particle size of interest to these applications is so small that they tend to stay suspended by Brownian motion even in one-g. However, convective stirring during heating and solidification can cause agglomeration of the fine dispersoids which can also lead to sedimentation.

Sedimentation/Buoyancy Effects

A number of materials, such as immiscible semiconductors, segregate when solidified in one gravity. In low gravity, phase separation and segregation can be better controlled. This has been demonstrated, using aluminum-antimony (AlSb), as shown here.

Under one-gravity conditions, low density materials will migrate toward the surface of a liquid (or melt). In low g, lighter density materials will remain in suspension for indefinite periods of time, thus removing a key constraint in the processing of composites and alloys where the constitutents have large density differences. Also, materials which must be stirred to remain in suspension in 1-g can be more effectively processed in low-g.

In this solidification experiment, ammonium chloride (liquid is light and crystals are dark) was used to simulate a casting process. Under one-gravity conditions, the dendrites formed and pieces broke-off and settled to the bottom of the container, thus producing weaknesses in the sample. In low g, the dendrites formed, grew uniformly and did not break off. This resulted in significant improvements in the sample.

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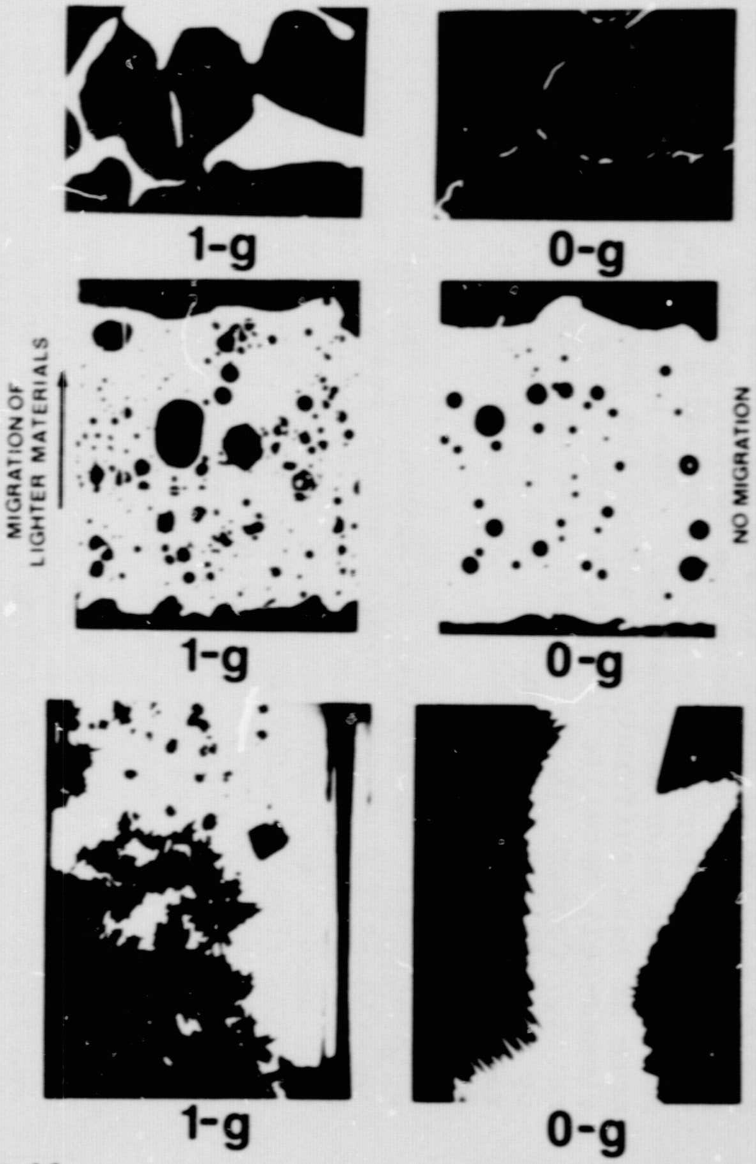


FIGURE 19

Another type of composite that may have interesting properties is uniform closed-cell metal forms. These could be formed by adding a "blowing agent" to a metal powder which would decompose into a gas just above the melting point. Graphite and a metal oxide, for example, could be added which will form carbon monoxide at high temperatures. The bubbles should nucleate more or less uniformly throughout the mixture, producing a closed-cell metallic foam with remarkable strength to weight ratio. Control of the bubble size and number should be possible by controlling the amount of gas produced and the production rate could be controlled by varying the amount of reactants and the temperature.

Suspensions: The ability to suspend a gas bubble in a liquid indefinitely provides several unique research opportunities. First, the effectiveness of glass fining agents can be studied. Such agents are added to melts in commercial glass to dissolve bubbles that form during the process. Since such bubbles also rise because of buoyant forces, it is difficult to study the effect of the fining agent by itself. A better understanding of how such agents actually work could lead to considerable energy and cost reduction in glass making.

It is also important to investigate the nucleation, growth, and coalescence of bubbles, flocculants, colloids, and hydrosols, and their behavior in thermal gradients and acoustic fields. Apart from fundamental interest, such studies have important applications in many industrial processes. For space processing applications, ways must be found to remove bubbles in the absence of buoyant forces that no longer operate in microgravity.

Immiscible Systems: The absence of buoyant forces allows the careful study of many physical chemistry problems in a way not otherwise possible. For example, there are many fluid systems that are immiscible because their molecules are so different that they do not attract each other nearly as well as they attract like molecules. A mixture of oil and water is a well-known example. As the temperature is increased, the entropy of mixing eventually increases to the point where a solution of the two would have the lowest free energy and the two liquids will dissolve in each other. The temperature at which immiscible liquids become miscible is called the consolute temperature.

The question now arises, what happens as a thoroughly-mixed immiscible system heated above the consolute is allowed to cool? On Earth, as soon as the immiscible phase begins to nucleate, the density difference between the two phases causes the two liquids to separate with the lighter fluid floating on the heavier fluid. In a weightless situation it should be possible to observe the growth of the individual droplets.

The total interfacial energy of a dispersion of fine droplets is much greater than one large globule (because of the surface area). Therefore, there will be a tendency for the droplets to aggregate.

If it is found that immiscible liquids can be prevented from separating during solidification, some exciting metallurgical applications may be possible. For example, there are some 500 metallic systems that have a miscibility gap. Alloys with these components cannot be prepared in bulk form on Earth because they separate due to density differences as soon as they are cooled below the consolute point. This offers a rich area to look for new systems that might have some interesting mechanical and electrical properties such as high transition temperature superconductors that can be easily drawn into wire, unique bearing material, improved electrical contact materials, high strength to weight alloys, etc.

Solidification Front Interactions: Another example of a physical chemical process that requires weightless to investigate is the interaction between a particle or a bubble and an advancing solidification front. There is a repelling force called the disjoining pressure that tends to push the particle ahead of the solidification front. On the other hand, there is also a drag force that opposes this motion. Therefore, it would appear that slowly moving solidification fronts would tend to exclude foreign particles or bubbles, but fast moving fronts would incorporate them. The question is, what is the critical speed and how does it relate to particle size, shape, composition, etc.? There is a theoretical treatment for the disjoining pressure developed by Lifshitz; however, the calculation is difficult because detailed knowledge of the optical constants of the material over the entire spectrum is required and generally is not well enough known. Since the forces involved are on the order of 10^{-5}g, such measurements can only be done in a weightless environment.

Monodispersed Latex Spheres: It was found quite by accident a number of years ago that a polyvinyl latex grown by polymerization of a monomer in presence of a surfactant and water yielded a vast number of microscopic spherical particles that were nearly identical in size. The size distribution was so narrow that the particles became widely used as calibration standards for electron microscopy. In a short time these monodispersed particles found a remarkable number of uses, ranging from seriological tests for a number of diseases to measuring pore sizes in biological and other membranes.

During the growth process, the latex spheres are kept in suspension by Brownian motion until they reach about two microns at which point they tend to sediment in 1-g. They can be kept in suspension by gentle stirring, but extreme care must be taken to prevent flocculation or the initiation of a new batch of

Monodisperse Latex Spheres

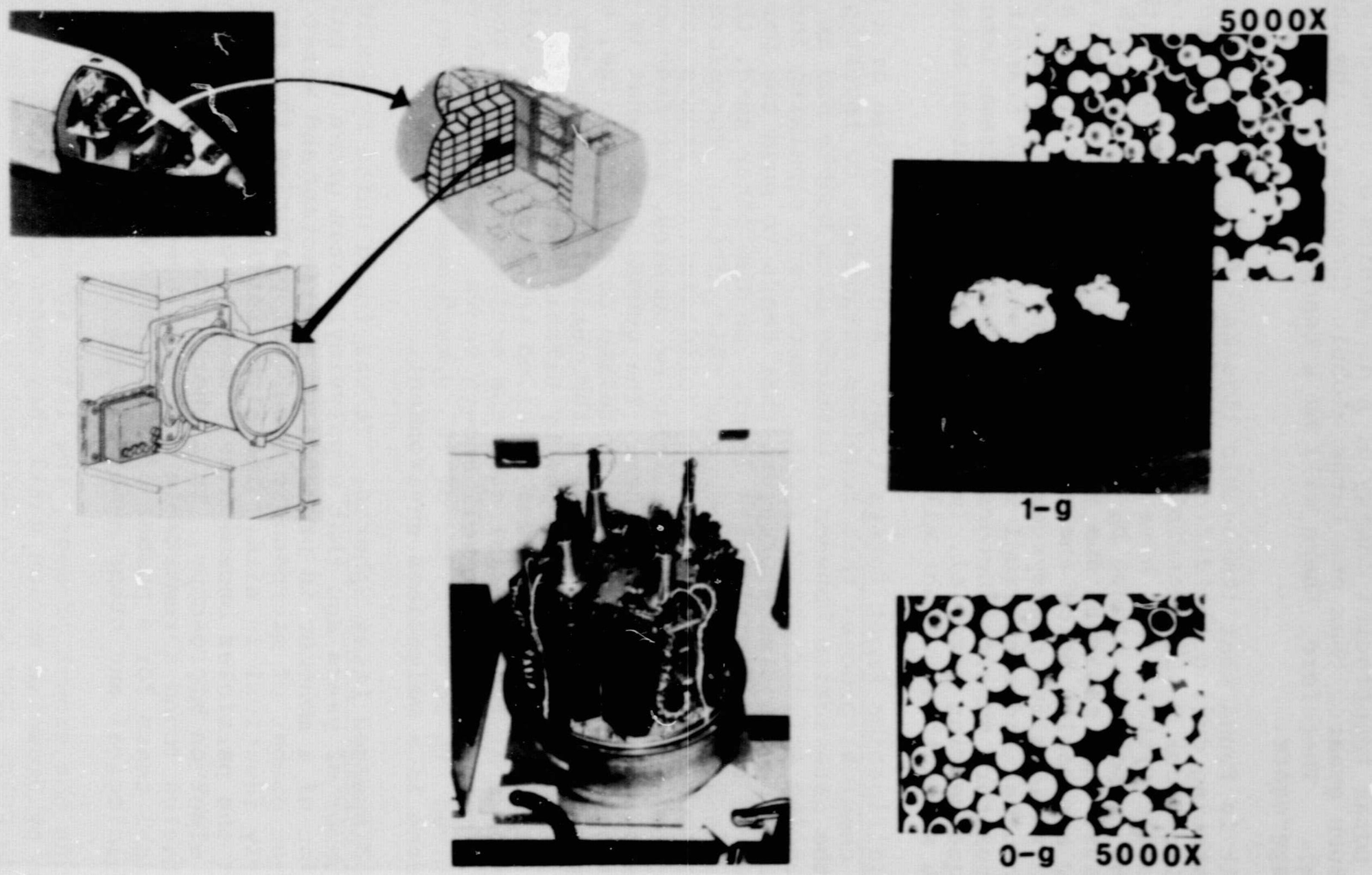


FIGURE 20

particles. For this reason, monodispersed spheres are not commercially available in sizes larger than two microns. It may be possible to produce larger monodispersed latex spheres by keeping them suspended in a weightless environment(Figure 20).

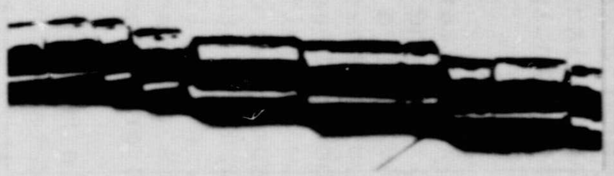
Hydrostatic Pressure Effect of Gravity

Strictly speaking, it is the lack of hydrostatic pressure that accounts for the absence of buoyant forces which result in the elimination of natural convection and sedimentation discussed previously. Another aspect of the lack of hydrostatic pressure is the elimination of the tendency for a liquid or solid to deform under its own weight (Figure 21). This means that liquids will take a shape that tends to minimize surface energy. Meniscii formed from between gas-liquid-solid, or liquid-liquid-solid interfaces will be determined solely by surface tension without hydrostatic distortion. This permits a more detailed investigation of a number of wetting and spreading phenomena, particularly such effects as contact angle hysteresis and moving interfaces. Other studies that can be aided by the lack of hydrostatic pressure include critical point phase transitions, the shape and stability of liquid bridges or floating zones, the coalescence of viscous droplets, etc. Again the objective is to perform an idealized experiment that is simple enough to compare with a tractable model. Consider how difficult it would have been to discover Newton's laws of motion had it not been possible to experiment with systems in which drag forces could be made negligible compared to inertial forces. Once the principle effect of surface forces is properly accounted for, the models can be extended reliably to consider hydrostatic forces present in Earth processes, just as drag forces can be incorporated into Newton's laws of motion once the basic principles are understood.

Critical Phase Transformations: Normally, gravitation plays a negligible role in molecular interactions, the one exception is near a phase transition critical point. As such a critical point is approached, the ensemble of molecules that are involved in thermal fluctuation is so large that the difference in gravitational potential over the ensemble becomes significant and the factors affecting the transition become dependent on gravity in a way that is not well understood. Furthermore, the times required to approach equilibrium are long, generally on the order of hours; therefore, such experiments are very logical candidates to be performed in a weightless environment.

Floating Zones: The ability to form stable molten zones that are considerably larger in length and diameter than possible on Earth permits a detailed study of this important crystal growth method. Of particular interest is the problem of Marangoni convection which is introduced by the fact that surface

Gravity Induced Deformation



1–g

This highly purified single crystal deformed along the shear planes under its own weight during processing in one gravity. Large crystals which have weak internal bonding strengths can be made in microgravity without deformation and with fewer defects.

1–g

0–g

Finished machined parts can be melted and resolidified in space without significant deformation when contained only by a thin skin of ceramic material as shown in the photographs at the left.

FIGURE 21

tension is dependent on temperature. Since a thermal gradient is required in the molten zone, a flow will result from the region of low surface tension to the region of high surface tension. The introduction of a surface contaminant such as an oxide layer or a liquid encapsulant will dramatically alter the surface tension and may be useful in controlling such flows. Float zone growth and refining is an important technique used on Earth. It is limited to materials and size configurations where the surface tension is large enough to contain the hydrostatic pressure. In space no such restriction exists (Figure 22). This has a major advantage in being able to tailor thermal profiles to produce sharp gradients and planar solidification interfaces essential to the prevention of constitutional supercooling and radial segregation in crystal growth. Also the float zone process in space will benefit by the improved control of concentration and temperature at the growth interface brought about by the absence of gravity-driven convection.

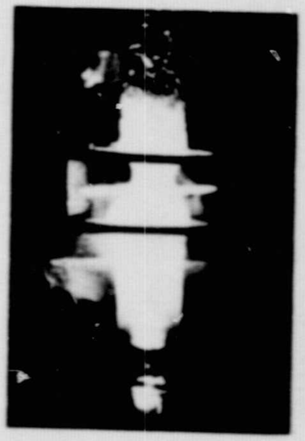
Distortional Influences: The absence of distortion from hydrostatic pressure may lead to other interesting applications. For example, it may be feasible to produce single crystal, intricate castings in a weightless environment by use of a thin oxide skin to preclude deformation. The casting might be coated with a thin layer of alumina to serve as a skin and taken to space for the final heat treat. The oxide skin would provide containment for the molten metal in 0-g, as well as enable very high thermal gradients which would be obviated in Earth-based molds.

Hydrostatic pressure also puts a strain in solids particularly when they are cooling just after solidification. Normally this is important only in large castings such as blanks for large telescope mirrors. However, there are certain crystals that are sufficiently delicate that they may suffer strain under their own weight at the growth temperature.

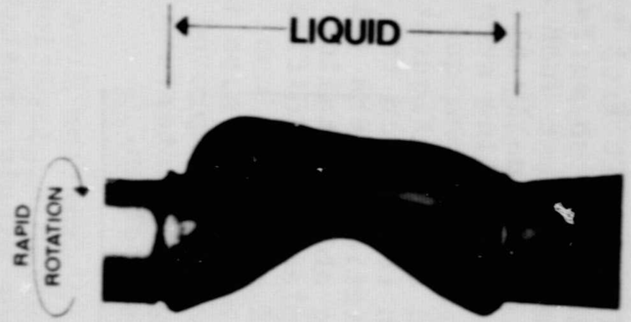
Containerless Processing: One of the most exciting prospects of processing materials in space is the ability to melt and resolidify materials without containment. It has already been mentioned that the shape of a liquid in a weightless environment will be controlled by surface tension. For a completely unconstrained liquid the equilibrium shape will be a sphere. In the condition of free fall, the sphere will remain essentially unaccelerated relative to the spacecraft. However, the small kinetic reactions due to the slight difference between the trajectory of the free floating sphere, together with the background jitter of the spacecraft and the residual velocity imparted to the sphere upon release, require an active position control if the sphere is to remain within the confines of the device or furnace for any length of time (Figure 22).

Containerless Processing

In the float zone process a bar of polycrystalline material is moved through the hot zone of a furnace in such a way that a thin molten zone moves along the bar and a single crystal is formed in the material solidified behind the zone. In low gravity, surface tension can hold a much larger molten zone in place, even if it is rotating rapidly as shown in the photograph at the far right.



TYPICAL 1-g FLOAT ZONE PROCESS



SIMULATED FLOAT ZONE IN 0-g

Gravity necessitates containment of a liquid (or melt) in a crucible. The crucible can contaminate the melt or produce unwanted nucleation sites, resulting in undesirable optical or physical properties in the material as illustrated in the photograph at the right.

In microgravity, containerless processing can be done by using weak acoustic, electromagnetic or electrostatic fields to position, manipulate and form molten materials. The picture at the far right shows a hologram of acoustic standing waves containing a glass being melted without the use of a container.

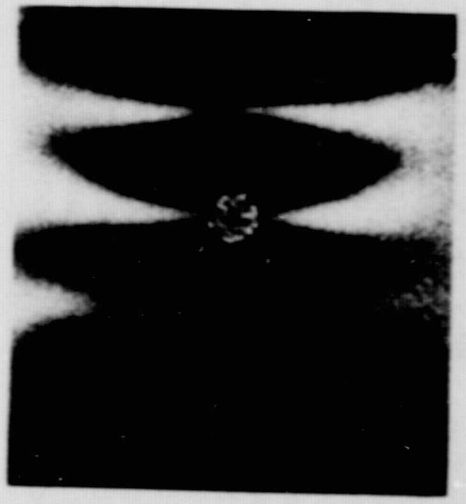


FIGURE 22

Position control can be accomplished in a variety of ways. If a gaseous environment is permissible, acoustic drivers can exert an acoustic radiation pressure on the sphere. By setting up a standing wave by means of a reflector, a stable acoustic well will exist at a quarter wavelength from the reflector, and the sphere will be retained in the center of this well provided the perturbing accelerations do not exceed the energy of the well (Figure 23). The use of three orthogonal drivers can produce three-axis positioning and by appropriate phasing can also provide rotational control.

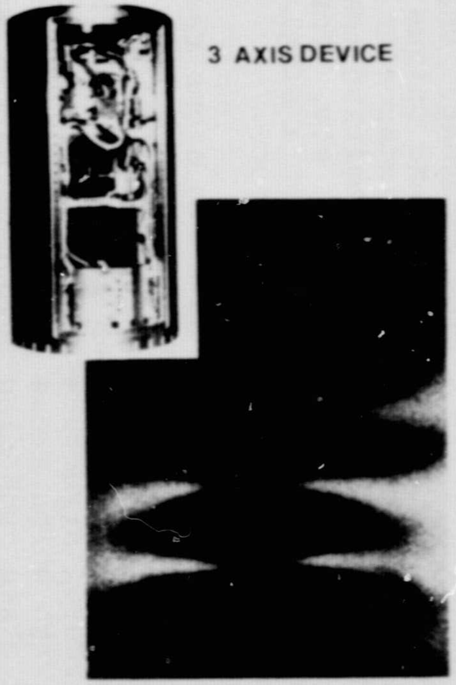
For systems requiring a vacuum environment, electromagnetic positioning can be used, provided the sample has some conductance. An RF field induces a current in the sample which in turn reacts to repel the inducing field. Figure 23 shows a baseball coil configuration which provides three-axis stability. Other mechanisms also exist for position control such as electrostatic repulsion, radiation pressure, or if there is a requirement to avoid any force on the sample, a container could be literally flown around the sample by means of control jets.

One of the principle advantages of containerless processing is the ability to eliminate wall effects such as contamination, nucleation, and induced strain. Since materials such as silicon and many of the oxide glass formers are highly reactive in the molten state (to the point of being universal solvents), considerable work has gone into minimizing container effects.

One of the most important applications for containerless processing is the ability to make unique glasses that cannot be made by convectional techniques. A glass differs from a crystalline solid by the fact that the long range order of a crystalline lattice is lacking. Also lacking are abrupt changes in lattice structure at the grain boundaries where crystal lattices of different orientations grow together. These differences are responsible for the useful and unique properties of glasses, i.e., optical clarity, resistance to grain boundary corrosion, the lack of a definite melting temperature, superior strength and mechanical properties, etc. For many applications a glass is a good substitute for a single crystal and is generally much less expensive to produce.

Virtually any solid substance could have its atoms rearranged into an irregular lattice to form an amorphous solid or glass. The tendency of a material to solidify into either a glass or a crystalline material depends on the relative difference in the energy of an ordered structure versus a disordered structure and the ease with which atoms can move about in the substance. Most good glass producing compounds have a small energy difference between ordered and disordered structure and are fairly viscous in the melt. Therefore, they can easily be solidified into the glassy state in which the viscosity continues to increase with decreasing temperature and the atoms

Containerless Processing

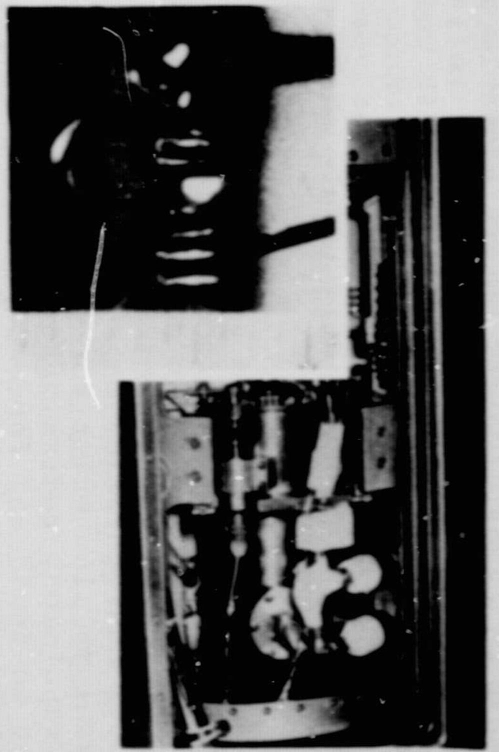


3 AXIS DEVICE

SINGLE AXIS FIELD

ACOUSTIC
LEVITATION

AERODYNAMIC
LEVITATION



ELECTROMAGNETIC
LEVITATION

FIGURE 23

become so sluggish that they never find the slightly lower energy configuration of crystalline lattice. On the other hand, most metals have large disordering energies and low viscosities. Therefore, their atoms will rapidly fall into an ordered array or crystalline lattice when cooled. A glassy state can be formed only by chilling the substance so rapidly that the atoms become frozen in place before they can arrange themselves in the lowest energy configuration. Metallic glasses can be formed by a process called "splat cooling" in which molten material is squirted against a cryogenic surface. Cooling rates in excess of 10^6°C/sec can be obtained in thin films by this process.

A molten material can be cooled well below its normal solidification temperature provided it is denied nucleation sites in the form of crystallites or impurity particles. If a material can be undercooled to achieve a sufficiently low viscosity before it solidifies, a glass will result. In many potential glass systems, the container wall provides nucleation sites and the material devitrifies (crystallizes) during solidification. Containerless processing can extend the ability to form glasses to a much wider range of materials than is currently possible, which may result in a wider range of choices for the optical designer in terms of optical properties such as index of refraction, transmissivity dispersion or Abbe number, etc. It was just such an increase in the availability of design choices, brought about by recent development of rare Earth glasses, that has vastly simplified lens design and reduced the number of components and cost required to make a high quality lens.

Another important application may be improvements in laser host glasses. In a laser, the lasing action is due to dopant atoms such as Nd or Cr imbedded in a host material such as ruby, ytterium aluminum garnet (YAG), or a variety of glasses. It has been found that, by increasing the content of calcia (CaO) in a Nd doped glass, the cross section for stimulated emission of the lasing line could be enhanced, resulting in a higher efficiency. Unfortunately, this increase also results in an increased tendency for the glass to devitrify. Containerless processing may extend the range of possible glass compositions that could be used as laser hosts and could result in significant advances in the technology.

The elimination of trace impurities such as submicron droplets of platinum or other crucible material in glasses becomes extremely important in high energy laser applications. Such dispersions may not be detrimental in many of the more pedestrian applications, but when high energy is passed through an optical component, localized absorption at such sites could have catastrophic results.

By the use of containerless techniques, it is possible to undercool many materials as much as several hundred degrees below their normal freezing temperatures. Theory tells us that the growth rate is proportional to roughly the cube of the amount of undercooling, so it may be appreciated that solidification when it does occur is almost explosive. The freezing front can move at velocities in excess of 500 m/sec. Such a process can produce similar results in a bulk sample that splat cooling can produce in a thin film. Amorphous or glassy forms of metals can be produced which combine the attractive properties of a glass with those of a metal. It is also possible to freeze metastable phases such as Nb_3 Ge and Nb_3 Sn that presently can only be produced in thin films or filaments. This would allow detailed study of the atomic structure of these materials using neutron diffraction and other characterization techniques that require a bulk sample and may provide valuable insights on why these particular structures are so much better superconductors than other structures.

Another application for containerless processing is the study of drop dynamics. The behavior of a free droplet has been the object of many theoretical studies, motivated by diverse applications ranging from the liquid drop models of the atomic nucleus to models of stellar processes. The measurement of the period of oscillation and the damping rate of a drop provides a very sensitive method for measuring surface tension and viscosity. For materials that are highly corrosive in the melt, a containerless process is required to determine these and other high temperature physical properties.

There are virtually no data available on the thermodynamic properties such as enthalpies, specific heats, heats of fusion, densities, and surface emissivities of liquids above 1000°C. These data are of interest for design of high temperature materials processes involving silicon, refractory oxides, sulfates, carbides, and nitrides. Containerless techniques not only avoid the corrosive reactions of these reactive melt with the crucible, but temperatures are not limited by the melting point of the crucible material.

Evaporative purification is another important application of containerless processing using electromagnetic levitation. At high powers, the induced currents not only provide positioning control and melt the sample, but can produce violent stirring within the sample. This can be very effective in removing materials more volatile than the host material. The ability to superheat can also produce a high density vapor of extremely pure material for vacuum distillation or physical vapor deposition.

The absence of buoyancy in containerless processes carried out in a weightless environment provides the opportunity to study problems such as bubble centering mechanisms in a droplet. For surfaces that are separated by only a few molecular layers, such as soap bubbles, surface tension acts to center the bubble and would provide a surface of uniform thickness were it not for gravitational distortion. What is not so obvious is whether there are much weaker, long range forces that would tend to provide a similar centering in droplets with thicker surfaces, such as hollow glass spheres.

Materials Science and Ultrahigh Vacuum

Ultrahigh vacuum processing may be accomplished in the shadow of a low outgassing shield designed to offer protection from the molecular beam resulting from moving through the residual atmosphere at orbital speed. Since any molecule evolving from the process is eventually lost to space, pumping capacity is virtually infinite. This is ideal for performing high temperature purification or vapor deposition on ultraclean surfaces.

There is considerable interest in the preparation of ultrapure materials. From the academic viewpoint it is of importance to determine and catalog the basic properties of materials. Such standard measurements should be made on the purest materials that can be prepared so that only the properties of the material of interest are considered. Even a slight trace of impurity can sometimes alter the properties of a material. For example, it is not presently known whether the lack of ductility of beryllium is an unusual property of that particular metal or whether it is due to residual impurities that cannot be eliminated in current preparation techniques.

There are also practical uses for ultrapure materials. For example, a large high purity single crystal of beryllium would be extremely useful as a neutron diffraction grating to produce a highly monoenergetic and well-collimated beam of neutrons from a nuclear reactor. Such a beam would be useful for a variety of experiments in neutron physics and, in particular, would serve as a powerful probe for use in the study of functional mechanisms of biological systems, cells, and organelles. Another possible application of such a space vacuum facility is the manufacture of low cost solar cells by vapor deposition of silicon on an ultraclean metallic substrate. Residual gas molecules on a substrate act as nucleation sites for the silicon vapor. If the surface is ultraclean, the vapor deposited silicon may form a large enough single crystal to produce an efficient solar cell. The temperatures required to clean the surface and evaporate the silicon are not compatible with the cryogenic pumped systems required to produce the necessary vacuum on Earth. Therefore, it may be economically advantageous to perform such manufacturing in space despite the high transportation cost.

Indigenous Space Materials Processing

The application of the 0-g research to terrestrial materials production is a primary goal of the MPS program, as is the use of the space environment for the processing of select terrestrial materials when transportation and processing is both technically and economically practical. There remains the ultimate step of processing materials indigenous to space -- in space -- for space applications (or perhaps on Earth). The in-situ mining, processing, and fabrication of materials entail exciting long term prospects as well as near term challenges in research and technology to establish the feasibility and practicality. Not only is it necessary to develop a unique "space chemistry" applicable to lunar, planetary, or astrodial materials, it is necessary to develop a commensurate automation and robotic technology to establish feasibility and facilitate eventual implementation.

Summary

With the extent of experimentation in microgravity environments to date, it has been clearly demonstrated that unique physical structures and property changes result from the elimination of the pervasive gravitational environment that dominates the production of all common materials on Earth. Figure 24 is a composite illustration of selected convective, buoyancy-sedimentation, and hydrostatic pressure effects of gravity on the various types of materials processing. Although impressive in contrast, the 0-g research to date has focused on how much remains to be understood about the common, although complex, processes used in the daily production of commercial materials. The isolation of gravitational effects and the unraveling of complex processes to permit the development of process technology and process controls to enhance material properties are the continuing NASA role through the MPS program. Figure 25 summarizes the experimental capabilities available and needed for the exploitation of 0-g technology in materials science and engineering, and the application of that technology to commercial interests in the private sector.

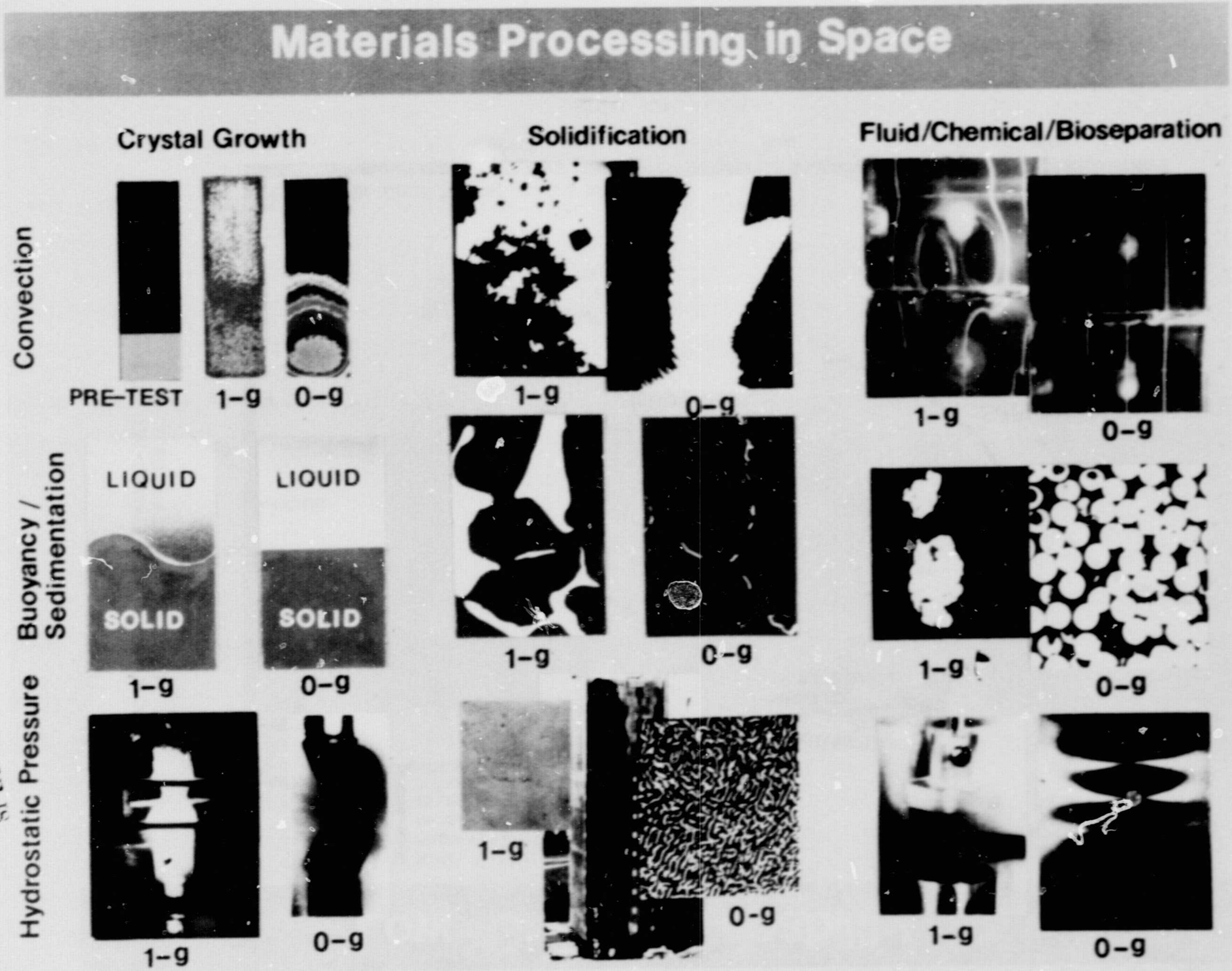


FIGURE 24

ORIGINAL PAGE IS
OF POOR QUALITY

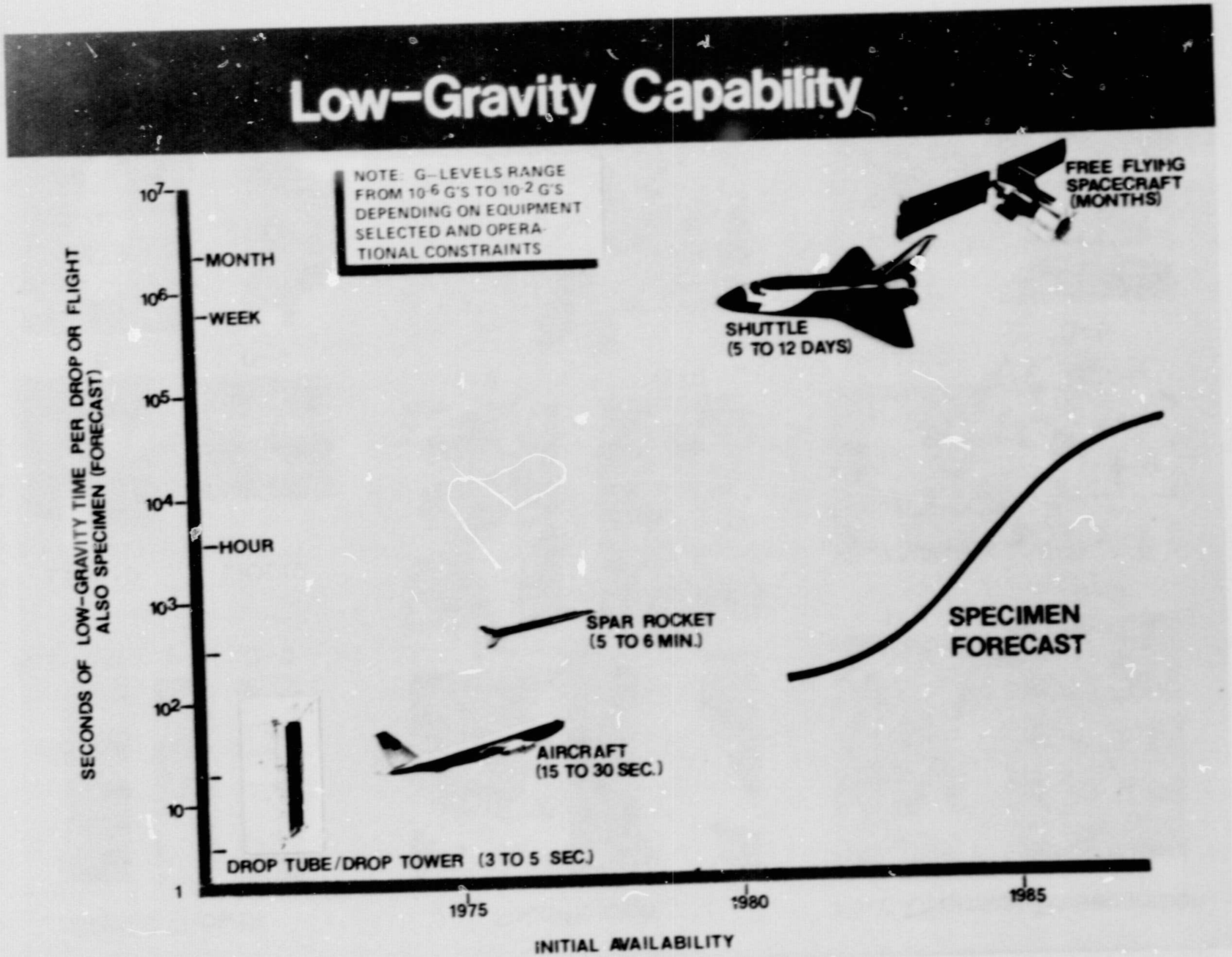

Low-Gravity Capability
NOTE: G-LEVELS RANGE FROM 10^{-6} G'S TO 10^{-2} G'S DEPENDING ON EQUIPMENT SELECTED AND OPERATIONAL CONSTRAINTS
SECONDS OF LOW-GRAVITY TIME PER DROP OR FLIGHT ALSO SPECIMEN (FORECAST)
10^7
10^6
10^5
10^4
10^3
10^2
10
1
MONTH
WEEK
HOUR
FREE FLYING SPACECRAFT (MONTHS)
SHUTTLE (5 TO 12 DAYS)
SPAR ROCKET (5 TO 6 MIN.)
AIRCRAFT (15 TO 30 SEC.)
DROP TUBE/DROP TOWER (3 TO 5 SEC.)
SPECIMEN FORECAST
1975
1980
1985
INITIAL AVAILABILITY

FIGURE 25

PROGRAM GOAL AND STRUCTURE

Program Goal

Succinctly stated, the goal of the MPS program is to define and demonstrate to the scientific and commercial user communities the capabilities of the space environment for materials science and engineering, and to provide the hardware systems and related operations support necessary and incidental to enable scientific and independently funded users to assess and exploit the space environment for advancing scientific knowledge and satisfying consumer needs.

NASA's primary roles in the ultimate realization of the stated goal are threefold:

a. On a continuing basis, sponsoring and stimulating the research, technology, and definition effort fundamental to the understanding and control of material science and engineering in microgravity.

b. Sponsoring the hardware development necessary and incidental to the accomplishment of the aforementioned research and technology, as required.

c. On a continuing basis, sponsoring or providing the payload systems, spaceflight integration, and operational support for NASA-sponsored research and, as appropriate, individually funded users.

It is imperative to thoroughly understand the influence of gravity on the individual physical and chemical mechanisms at work in specific material processes to determine if variation or elimination of perceptible gravitation forces will permit control of the processes and enhancement of the resultant materials. From these fundamental analyses, one may determine the gravitational limits of process controls for Earth-based applications, and the viability of processing in space. To effectively determine and convey the prospectus for processing in space to the user communities, unambiguous examples and demonstrations are needed.

The research and technology pursuits are intended to be discipline oriented, and are derived from the materials processing technologies anticipated to have significant commercial applicability; the resultant MPS research priorities (not ordered in the listing) are:

a. Crystal Growth Processes

b. Solidification Processes

c. Fluid and Chemical Processes

d. Biological Separation Processes

e. Vacuum Processes

f. Containerless Processes

Typically, the realization of the MPS program goals, as related to any specific discipline, would evolve technologically and programmatically through a sequence of events as shown pictorially in Figure 26 and summarized as follows:

- Ground-based Research and Analysis
  - Precursory Microgravity Experiments in Drop Towers, Aircraft Parabolic Flights, Sounding Rocket Flights, Etc.
    - Spaceflight Scientific and Payload Requirements Definition
      - Experimental Payload Development
        - Orbital Spaceflight Experiments for Process Analysis and Demonstration
          - Commercialization Through Joint Endeavors and Privately Funded Ventures
            - Exploitation of Space Indigenous Materials

NASA expects to sponsor pioneering research and spaceflight experimentation to establish a technological basis for commercial ventures in all of the aforementioned discipline areas.

Prerequisite to the elicitation of commitments from individually funded users is the establishment of the legal and managerial precepts and framework that protect the rights, interests, and investments of the user communities and, at the same time, provide due consideration to national interests. Obviously, analogous, but different, criteria must be applied to the selection and execution of scientific and commercial endeavors: whereas research activity may have scientific imperatives if not unambiguous utilitarian application; a commercial venture may lack scientific pedigree, but offer substantive profit motivation.

Implementation Of MPS Program Goals

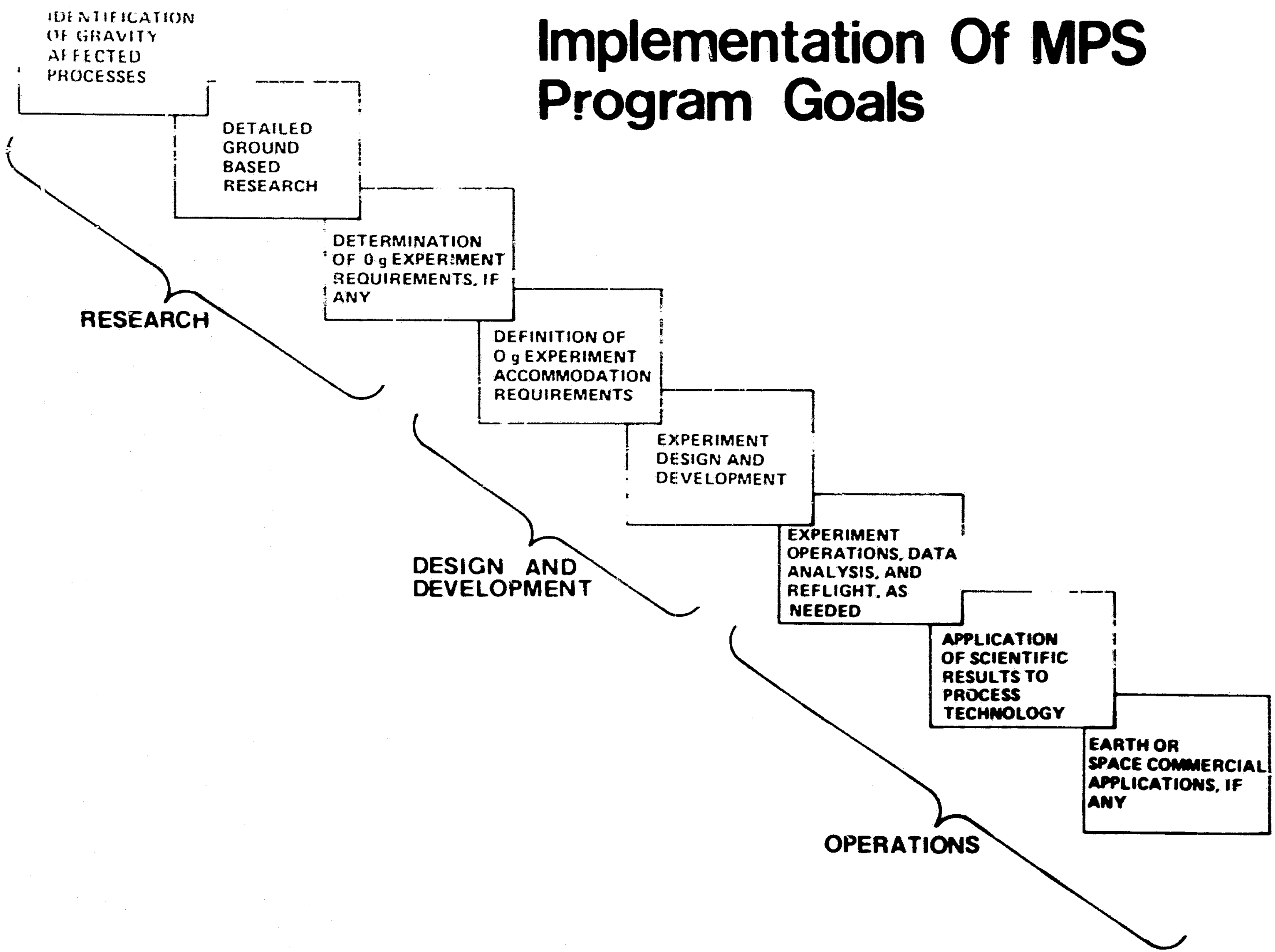


FIGURE 26

An imprudent business arrangement, even if the government does not suffer a financial loss, will have as lasting and detrimental effects on the NASA applications program as an unsound scientific venture. Based upon the express requirements of the scientific or commercial user communities, experimental or processing facilities must be developed, validated, integrated, and operated, either on the ground or in space, to obtain the needed data or materials. To these ends, NASA is implementing and executing a multifaced and comprehensive program which, as illustrated in the Introduction, is intended to address the full spectrum of needs of and be responsive to the user communities.

Programmatic Structure

The enabling programmatic structure (basically the UPN budget structure) is designed to be compatible with the NASA roles and responsibilities in the implementation of the Program Goals. The program is organized, funded, and executed, in a typically chronological fashion, through the following UPN's:

UPN 179 - MPS Applications Research and Data Analysis (AR&DA)
UPN 674 - MPS Shuttle/Spacelab Payload Development
UPN 6xx - MPS Materials Experiment Operations

The content and interrelationships of the UPN's are defined as follows:

AR&DA - UPN 179

NASA has a continuing role and responsibility in sponsoring innovative research to ascertain the gravitational and other pertinent space environmental effects upon material processes and to scientifically characterize the nature and extent of process control that can be achieved through variation of or compensation for gravitational forces. The effort, necessarily starts with ground-based research to define the material formation processes and to isolate the gravitational influences on those processes. Where elimination of gravity would contribute to examination of process interactions or control of the processes, microgravity experiment requirements are defined and analyzed with the objective of developing spaceflight experiments. Often precursory type experiments employing space simulation techniques such as neutral buoyancy, drop tubes, parabolic flights with aircraft, or sounding rocket flights, either can provide the required microgravity data or serve as incremental steps in the process definition and demonstration. From scientific experiment requirements predicated upon ground-based research and simulations, the definition and design

requirements for supportive spaceflight payload hardware are derived where long term (i.e., orbital) microgravity exposure is required and justified in materials process analyses and applications.

The UPN 179, "AR&DA," embraces the sustaining research and technology activities fundamental and necessary to the realization of the MPS program goals. The UPN 179 is structured with the following content:

- Supporting Research and Technology (SRT)

  Crystal Growth Process Research
  Solidification Process Research
  Containerless Processing Research
  Fluid and Chemical Process Research
  Biological Separation Process Research
  Vacuum Processing Research

- Applications Technology Development (ATD)

  Process Technology Development (Including Automation)
  Payload Technology Development
  Low-g Simulation Technology
  Extraterrestrial Materials Processing Technology (Including Machine Intelligence and Robotics)

- MPS Payload Definition Studies

  Phase A and Phase B Studies Consistent With Planned New Activities

The areas of research (RTOP's) under SRT are intended to be long term, comprehensive programs composed, primarily, of contracted research efforts with PI's whose work has been selected through a peer review process under the AN system. The RTOP's represent areas wherein gravitational forces and/or other elements of the space environment are known and have been demonstrated to have a significant effect upon the process variables, and wherein significant commercial potential exists. The research program in each area is developed to systematically isolate and analyze the process variables essential for applications. The sponsored research is selected within the context of the existing data base in the materials science and processing disciplines, and within the context of work sponsored or anticipated by other sources.

The areas of technology (RTOP's) under ATD, are intended to provide the techniques, proof-of-concept, and breadboard activities to permit implementation of the MPS research program

through the necessary and incidental payload hardware development efforts. This effort is essential and complementary to the research program in that it will preclude or minimize high programmatic and, possibly, scientific impacts to the hardware development activities. The technology areas are derived from the commonality of design requirements and state-of-the-art advances that permeate through all of the payload hardware developments that have been defined and forecast from the ground-based research. The technology effort is anticipated to be largely based upon contracted study efforts augmented by NASA inhouse expertise.

The Phase A and Phase B definition studies are the natural extension of the SRT and ATD through the predevelopment aspects of the NASA-phased project planning philosophy leading to the agency commitment for a new start of new initiative. The definition studies provide the engineering insight and industrial planning base for the hardware procurements.

Figure 27 relates the aforementioned SRT disciplines to the types of experimental devices that would be required for accomplishment of the PI investigations; Figure 28 extends the analysis to accommodation requirements for the various types of experimental devices, envisioning at least three levels of study: (a) exploratory research using relatively simple devices, (b) process analysis involving detailed, well instrumented investigations, and (c) demonstration of the ability to control material processes through the application of results of the prior investigations. Figure 29 relates the thrust of the ground-based research toward eventual, potential commercial applications in a chronological and programmatic sense through the identity of the MPS payloads and accommodation modes which are anticipated for the investigation and demonstration of gravitational forces and other elements of the space environment in the controlling process within each research area.

MPS Shuttle/Spacelab Payload Development - UPN 674

As a necessary and incidental adjunct to the realization of the program goal, spaceflight payloads are needed in which to conduct the research, demonstrations, and preparation of exemplary materials. Subsequent to a well characterized ground-based research program, and appropriate technology and definition studies, and upon commitment of the agency to proceed with new starts or new initiatives, the design, development, and support activities associated with MPS payloads will be accomplished under UPN 674. The payload development activities entail the following:

EXPERIMENTAL CAPABILITY REQUIREMENTS

RESEARCH DISCIPLINES / TYPICAL EXPERIMENT CAPABILITY REQUIREMENTS	SOLUTION GROWTH CELL	ISOTHERMAL FURNACE	GRADIENT FURNACE	DIRECTIONAL FURNACE	ACOUSTIC LEVITATOR	ELECTROMAGNETIC LEV.	ELECTROSTATIC LEV.	ELECTROPHORESIS	ISOELECTRIC FOCUSING	COUNTER CURRENT	FLOAT ZONE FURNACE	VAPOR GROWTH FURNACE	FLOW VISUALIZATION	DROP TUBE	SPACE VACUUM FACILITY
CRYSTAL GROWTH PROCESSES															
• MELT GROWTH PHENOMENA				X											
• SOLUTION GROWTH PHENOMENA	X														
• VAPOR GROWTH PHENOMENA			X									X			
• FLOATING ZONE GROWTH PHENOMENA											X				
SOLIDIFICATICN (METALLURGICAL) PROCESSES															
• CASTING PHENOMENA		X	X												
• DIRECTIONAL SOLIDIFICATION PHENOMENA				x											
• UNDERCOOLING PHENOMENA					X	X	X							X	
CONTAINERLESS PROCESSES															
• NUCLEATION AND SOLIDIFICATION PHENOMENA					X	X	X							X	
• SHAPING AND FORMING PHENOMENA					X	X	X								
• ULTRAPURIFICATION PHENOMENA					X	X	X				X				X
• THERMOPHYSICAL MEASUREMENTS					X	X	X				X				
FLUID AND CHEMICAL PROCESSES															
• BUBBLE AND DROP DYNAMICS					X		X						X		
• FLUID DYNAMICS													X		
• THERMOPHYSICAL PHENOMENA													X		
• PHYSICOCHEMICAL PHENOMENA													X		
BIOLOGICAL SEPARATION PROCESSES															
• ELECTROKINETIC SEPARATION PHENOMENA								X	X				X		
• PHASE PARTITIONING PHENOMENA								X		X			X		

FIGURE 27

FUNCTIONAL REQUIREMENTS (EXEMPLARY)	EXPLORATORY			PROCESS ANALYSIS					PROCESS CONTROL				
	OPERATING MODE	POWER LEVEL (KW)	ACCOMMODATION MODE	OPERATING MODE	SAMPLE LOT (NO.) MINIMUM	POWER LEVEL (KW)	MISSION TIME (DAY) MINIMUM	ACCOMMODATION MODE	OPERATING MODE	SAMPLE LOT (NO.) MINIMUM	POWER LEVEL (KW)	MISSION TIME (DAYS) MINIMUM	ACCOMMODATION MODE
CRYSTAL GROWTH PROCESSES													
• DIRECTIONAL SOLIDIFICATION FURNACE	AUTO	2	STS	AUTO	5	1-5	6	STS	AUTO	5	5-15	100	FF
• SOLUTION GROWTH CELLS				MAN	6	1-5	10	STS	AUTO	10	5-10	30	FF
• HIGH GRADIENT FURNACES				AUTO	6	1-5	6	STS	AUTO	10	5-10	40	FF
• VAPOR GROWTH FURNACES				MAN	2	1-5	10	STS	AUTO	10	10-15	60	FF
• FLOAT ZONE FURNACES				MAN	3	1-5	7	STS	AUTO	5	10-15	100	FF
SOLIDIFICATION (METALLURGICAL PROCESSES													
• ISOTHERMAL FURNACES	AUTO	1	STS	AUTO	6	1-2	3	STS	AUTO	25	5-15	25	FF
• DIRECTIONAL SOLIDIFICATION FURNACE	AUTO	2	STS	AUTO	6	1-2	6	STS	AUTO	25	5-10	25	FF
• LEVITATION DEVICES	AUTO	2	STS	AUTO	10	1-5	2	STS	AUTO	20	5-15	10	FF
CONTAINERLESS PROCESSES													
• ACOUSTIC LEVITATION FURNACE	AUTO	2	STS	AUTO	10	1-3	2	STS	MAN	100	10-15	10	ST'
• ELECTROMAGNETIC LEVITATION FURNACE	AUTO	2	STS	OR	10	1-3	2	STS	OR	100	10-15	2	OR
• ELECTROSTATIC LEVITATION FURNACE				MAN	10	1-3	2	STS	AUTO	100	10-15	10	FF
FLUID AND CHEMICAL PROCESSES													
• LEVITATION DEVICES	AUTO	2	STS	MAN	10	1-3	5	STS					
• FLOW VISUALIZATION CELLS	AUTO	1	STS	MAN	6	1-3	10	STS					
BIOLOGICAL SEPARATION PROCESSES													
• ELECTROPHORESIS DEVICES	AUTO	1	STS	MAN	5	1-5	10	STS	MAN	10	5-10	90	FF
• ISOELECTRIC FOCUSING DEVICES				MAN	5	1-5	10	STS	OR	10	5-10	90	FF
• COUNTER CURRENT DEVICES				MAN	5	1-5	10	STS	AUTO	10	5-10	90	FF

LEGEND: AUTO-AUTOMATED OPERATION
MAN-MANUAL OPERATION
STS-SPACE TRANSPORTATION SYSTEM
FF-FREE FLYER

FIGURE 28

PROGRAM EVOLUTION

Research Discipline (UPN 179)	Experimental Payloads (UPN 674)	Spaceflight Modes (UPN 6xx)	Potential Commercial Applications
Crystal Growth Processes ● Diffusion Controlled Growth Phenomena ● Vapor Growth Phenomena ● Solution Growth Phenomena ● Epitaxial Growth Phenomena ● Floating Zone Growth Phenomena	Fluids Experiment Sys. (D)* Vapor Crystal Growth Sys. (D) Analytical Float Zone Sys. (B) Solidification Experiments Sys. (D) Float Zone Processing Sys. (A) Epitaxial Crystal Growth Sys. (I) High Gradient Furnace (A)	Orbiter Middeck Spacelab Module Spacelab Pallet Materials Experiment Assembly Materials Experiment Carrier (Power System - Free Flying)	Infrared Detectors Nuclear Detectors Solar Cells Doped Semiconductor Chips
Solidification Processes ● Microsegregation Phenomena ● Macrosegregation Phenomena ● Dispersion Phenomena	Solidification Experiments Sys. (D) Fluids Experiment Sys. (D) High Gradient Furnace (A)	Orbiter Middeck Spacelab Pallet Spacelab Module Materials Experiment Assembly Materials Experiment Carrier (Power System - Free Flying)	Dispersed Composites Directionally Aligned Materials Castings Solar Cells Eutectic, Peritectic, and Multiphase Alloys Metal Foams Superconductors Miscibility Gap Alloys

*Legend: A - Under Feasibility Study
B - Under Preliminary Design
D - Under Design and Development
I - Under Industrial Consideration

FIGURE 29

PROGRAM EVOLUTION

Research Discipline (UPN 179)	Experimental Payloads (UPN 674)	Spaceflight Modes (UPN 6xx)	Potential Commercial Applications
Fluid and Chemical Processes • Gravity Driven Convection Phenomena • Non-g Driven Convection Phenomena • Drop Dynamics • Segregation and Flocculation Phenomena • Sterochemical Phenomena	Monodispersed Latex Reactor (D) Fluids Experiment System (D) Polymer Latex Reactor (A) Combustion Facility (A) Drop Dynamics Module (D)	Orbiter Middeck Spacelab Module Materials Experiment Carrier (Power System - Free Flying	Polymers Monodisperse Latexes
Biological Separation Processes • Electrophoresis Phenomena • Isotachophoresis Phenomena • Counter Current Phenomena • Isoelectric Focusing Phenomena • Cell Culturing Phenomena	Isoelectric Focusing System (B) Electrophoresis System (A/I) Fluids Experiment System (D) Bioprocessing System (A) Fluids Experiment System (D)	Orbiter Middeck Spacelab Module Materials Experiment Carrier (Power System - Free Flying)	Purified Hormones, Enzymes, Vaccines Purified Products of Live Cells: Blood Fraction Cell Cultures to Produce Immunologic Products

PROGRAM EVOLUTION

Research Discipline (UPN 179)	Experimental Payloads (UPN 674)	Spaceflight Modes (UPN 6xx)	Potential Commercial Applications
Vacuum Processes • Vapor Deposition Phenomena • Vapor Crystal Growth Phenomena • Outgassing and Sublimation Phenomena	Wake Shield Demonstration (A) Electromagnetic Containerless Processing System (A) Space Vacuum Research Facility (A)	Space Shuttle Materials Experiment Carrier (Power System - Free Flying) Wake Shield Free Flyer (Power System)	Purified Metals Vacuum Deposited Solar Cells
Containerless Processes • Nucleation and Solidification Phenomena • Vapor Crystal Growth Phenomena • Bubble Motion & Control Phenomena • Mixing and Shaping Phenomena • Extreme Undercoding Phenomena	Acoustic Containerless Experiments System (1-axis) (D) Drop Dynamics Module (D) Acoustic Containerless Processing System (3-axis) (B) Electromagnetic Containerless Processing System (A) Electrostatic Containerless Processing System (A)	Spacelab Pallet Spacelab Module Materials Experiment Assembly Materials Experiment Carrier (Power System - Free Flying)	High Index of Refraction Glass Fiber Optics Optical Wave Guides Laser Host Glass Microspheres, Fusion Targets Bulk Glassy Electromagnetic Materials Ultrapure Metals Variable Index of Refraction Glass Lenses Super Alloys Superconductors Property Measurements (High Temperature, Reactive Materials)

Payload Design and Development
Payload Integration Support for Initial Mission
Initial Mission Operations Support
PI Experiment Development
PI Experiment Support

Relative to the Shuttle ground operations flow, UPN 674 provides for Prelevel IV integration, and the support to the Level IV-I integration that may be required from the MPS payload developer and the PI's. Level IV-I integration expenses are to be budgeted by the appropriate Mission Management Office commensurate with payload mission assignments from other appropriate fund sources. Real time mission operations support, if required by either the MPS payload developer or the PI's, would be included in UPN 674. Payload specialist training and mission activities are to be funded from other sources through the Mission Management Office, including those specialized activities or training required in conjunction with the PI experiment development. The PI experiment development provides for the analyses, ground-based research, precursory experimentation, ground control and flight sample preparation, real time mission support, and post-flight analyses. NASA-sponsored scientific flight experiments are selected through a peer review of responses to an Announcement of Opportunity (AO); commercial application flight experiments originating from joint endeavors or reimbursable flight opportunities are supported to the extent appropriate under UPN 6xx, "Materials Experiment Operations." PI experiment support is essential to accommodate special analyses, testing, and hardware support unique to the PI's experiment development and implementation. Operations associated with precursory experimentation and with the Ground Control Experiment Laboratory (GCEL), because of their sustaining and generalize support, are funded from UPN 6xx, "Materials Experiment Operations," although the original procurement of GCEL hardware is generally a part of the development contract.

Currently, the MPS payloads to support the Spacelab 3 mission and a shared satellite deployment mission are being developed under UPN 674. Additional Shuttle or Spacelab MPS payload items are required and will be pursued to meet the scientific demands of the various research areas evolving from UPN 179, AR&DA. A free-flying experiment capability is essential for MPS to achieve the low cost per sample essential for multiple sample research programs and commercial applications, as well as to achieve long low-g processing times and to satisfy high power, energy, and heat rejection demands. Consistent with the advent of an interim free flyer and/or a power system and the Materials Experiment Carrier (MEC), to be developed by OSTS, supporting payload developments will be pursued under UPN 674.

Similarly, payload developments for other payload carriers are anticipated under UPN 674 as they materialize. Figure 30 provides a listing and anticipated development schedule for MPS payloads included under UPN 674. The composite of these experimental facilities constitutes a national materials research capability that will be routinely available for scientific and commercial users.

MATERIALS EXPERIMENT OPERATIONS - UPN 6xx

Pursuant to NMI 8010.1, "Classification of NASA Space Transportation System (STS) Payloads," all MPS payload hardware is intended and designed for repeated operations and economy (Class C), and nearly all PI's require multiple samples and multiple reflight opportunities to accomplish experimental objectives. MPS microgravity experimentation, responsive to the needs of the PI's, is accommodated through a wide variety of test capabilities:

	Typical Microgravity Duration
Drop Towers and Drop Tubes	2-4 seconds
Aircraft and Parabolic Flights	20-40 seconds
Sounding Rockets (SPAR)	4-6 minutes
Space Shuttle	
MEA	$\leq$ 7 days
Spacelab Module	7-30 days
Spacelab Pallet	7-14 days
MEC	Long Duration
Space Vacuum Research Facility (SVRF)	Long Duration

Much of the MPS payload equipment can and will be employed on a number of payload carriers; for example, the single-axis acoustic levitator designed for the SPAR is to be utilized on the MEA with the addition of an automatic sample changer, potentially, on the Spacelab pallet, and, ultimately, with some modification, on the MEC. Because of the interchangeability of hardware, the changing payload/investigator mission manifests, and the long term, sustaining operational nature of the MPS operational activities, UPN 6xx is intended to consolidate those activities to insure proper management control, continuity of scientific support, consistency in procedures and documentation control, and elimination of duplicative effort.

UPN 6xx, "Materials Experiment Operations," includes all of the sustaining operations such as:

MPS EXPERIMENTAL APPARATUS

EXPERIMENTAL APPARATUS	APPROX. AVAILABILITY	TYPICAL ACCOMMODATION
Isothermal General Purpose Rocket Furnace (I-GPRF)	Existing	SPAR, MEA
Gradient General Purpose Rocket Furnace (G-GPRF)	Existing	SPAR, MEA
Thermal Control Unit (Furnace) (TCU)	Existing	SPAR, MEA
Directional Solidification Furnace (DSF)	Existing	SPAR, MEA
Directional Solidification Apparatus	Existing	SPAR, MEA
Dendrite Remelting Device	Existing	SPAR, MEA
Dendrite Solidification Device	Existing	SPAR, MEA
Epitaxial Crystal Growth Apparatus	Existing	SPAR, MEA
Bubble Migration Apparatus	Existing	SPAR, MEA
Glass Fining Apparatus	Existing	SPAR, MEA
Electromagnetic Levitation Furnace	Existing	SPAR, MEA
Single-Axis Acoustic Levitator Furnace	Existing	SPAR, MEA
Three-Axis Acoustic Levitator	Existing	SPAR, MEA
Electrophoretic Separation	Existing	SPAR, MEA, Orbiter Middeck
Monodispersed Latex Reactor (MLR)	Existing	Orbiter Middeck
Fluids Experiments System (FES)	1983	Spacelab Module
Vapor Crystal Growth System (VCGS)	1983	Spacelab Module
Electrokinetic Separation System (ESS)	Mid 80's	Spacelab Module
Float Zone Experiment System (FZES)	Mid 80's	Spacelab Pallet
Acoustic Containerless Experiment System (ACES)	Mid 80's	Spacelab Pallet
Electrostatic Containerless Experiment System (ESCES)	Late 80's	Spacelab Pallet
Solidification Experiments System (SES)	1983	Spacelab Pallet, MEC
Acoustic Containerless Processing System (ACPS)	Mid-Late 80's	MEC
High Gradient Furnace System (HGFS)	Mid-Late 80's	MEC
Float Zone Processing System (FZPS)	Mid-Late 80's	MEC
Electromagnetic Containerless Processing System (EMCPS)	Mid-Late 80's	MEC
Electrostatic Containerless Processing System (ESCPS)	Mid-Late 80's	MEC
Bioprocessing System (BPS)	Mid-Late 80's	MEC

FIGURE 30

- Precursory Test, Integration and Operations Support

  Ground Simulation Facilities Such as Drop Tubes and Drop Towers
  Aircraft Flights
  Sounding Rocket (SPAR) Flights (Nominally, Two Per Year)

- Orbital Reflight Integration and Operations Support for MPS Payload Carriers and Accommodation Modes

  MEA (Nominally, 2-3 Flights Per Year)
  Spacelab Module MPS Payloads (Nominally, 1-2 Flights Per Year)
  Spacelab Pallet MPS Payloads (Nominally, 2 Flights Per Year)
  MEC (Nominally, 4 Reservicing Flights Per Year)
  SVRF
  Orbiter Middeck (Nominally, 6 Flights Per Year)

- Reflight Mission Operations Support

- Payload Refurbishment, Reconfiguration, Modification, Replacement, and Reverification (Including the MPS Peculiar Payload Carriers/Spacecraft)

- PI Experiment Development for Payload Reflights

- PI Experiment Support for Payload Reflights

- GCEL Operations

- Commercial Applications (Joint Endeavor and Reimbursable Flight Opportunities) Support

The precursory test integration and operations support provides the following:

- Ground Simulation Facilities Repair, Modification, Operation and Associated Experiment Specimen Preparation

- Aircraft Payload Refurbishment, Modification, and Reverification; Payload Assembly and Integration; and Aircraft Use Charges

- Sounding Rocket (SPAR) Payload Refurbishment, Modification, Reverification; Payload Assembly and Integration; Launch Vehicle Integration; and Launch Operations

Orbital reflight integration and operations support embraces the Prelevel IV integration, and the support to the Level IV-I integration that may be required for the MPS payload integrator and the PI's. Level IV-I expenses are to be budgeted by the appropriate Mission Management Office commensurate with payload mission assignments from other appropriate fund sources. Real time reflight mission operations support, if required by either the MPS payload integrator or the PI's, would be included under UPN 6xx. Payload specialist training and mission activities are to be funded from other sources through the Mission Management Office, including those specialized activities or training required in conjunction with the PI experiment reflight work.

Payload refurbishment, reconfiguration, modification, replacement, and reverification provide the overall effort associated with the hardware, software, and documentation maintenance to accommodate the scientific and operational requirements. The reflight PI experiment activity provides analyses, ground-based research, ground control and flight sample preparation, real time mission support, and post-flight analyses. Reflight PI experiment support accommodates the special analyses, testing, and hardware support unique to the PI's experiment implementation.

An essential element of spaceflight experimentation is the establishment of ground-based reference data for use in post-flight analyses. To the extent possible, the reference specimens and data must be prepared under conditions which duplicate the spaceflight conditions with the exception of the gravitational environments. The GCEL is composed of experimental equipment which is functionally identical to the flight hardware in which preflight reference specimens and data are obtained. To insure functional compatibility between GCEL and flight payload hardware, both devices must be maintained under the same configuration control system. The sustaining operation and control of the GCEL is provided under UPN 6xx.

Commercial applications entail considerable preparatory work with the private sector to find a mutually beneficial basis for cooperative or privately funded ventures. The culmination of the preparatory work is generally realized in NASA providing integration and operations support either in a reciprocal arrangement (joint endeavor) or on a reimbursement basis. This is due to the fact that few private sector investigators have the experience and expertise with spaceflight hardware to assume those responsibilities initially on their own. While NASA might assist in the development of commercial payload hardware, the overall thrust of the commercial application effort is to provide a self-supporting, sustaining operational basis for the exploitation of the space environment for the public benefit through the private sector; therefore, the multifaceted commercial applications are included under UPN 6xx.

PROGRAM MANAGEMENT

Organization

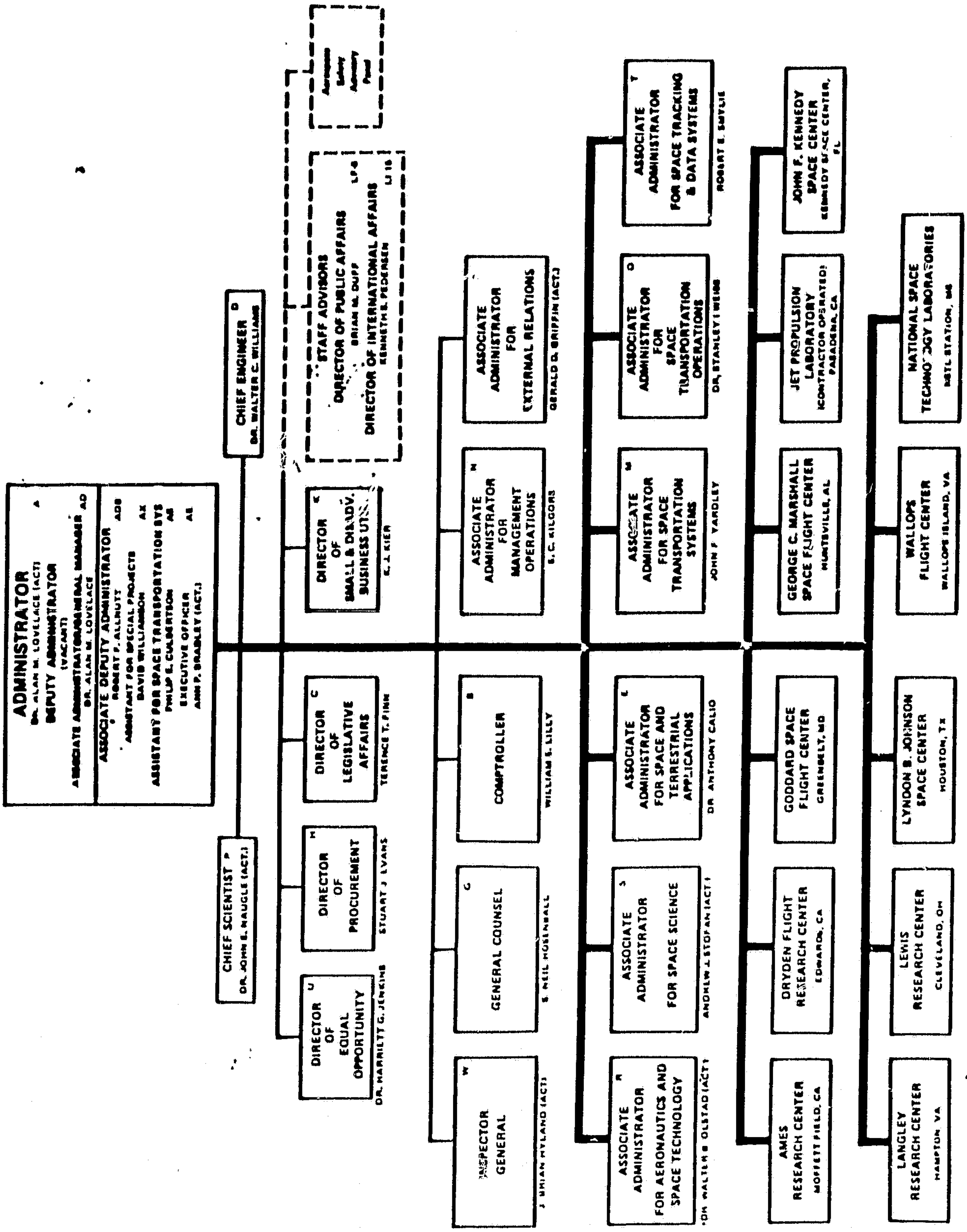
The NASA MPS program is the responsibility of the Associate Administrator for the Office of Space and Terrestrial Applications (OSTA) and is directed and administered by the Director, MPS Division, at NASA Headquarters (Figures 31 through 33). The Division Director is supported directly in the overall management and execution of the program by the MSFC MPS Projects Office (Figures 34 and 35). The projects office depends upon the laboratories of the MSFC, other NASA centers, other government agencies, universities, institutions, and the private sector for technical support and program implementation.

In consonance with the recommendations of the STAMPS committee, a Scientific Advisory Committee has been formed, responsive to the MPS Division Director, to aid in future program planning and policy making relative to scientific aspects of the program. Peer groups have been empaneled to assist in the selection and periodic review of scientific experimentation, and the periodic review of plans and policies. A commercially oriented Advisory Committee may be formed to provide guidance and assistance in planning and policy in an equitably balanced program management.

The Director, MPS Division, OSTA, determines program policy, objectives and priorities, and controls the allocation of program resources. OSTA is additionally responsible for science policy, objectives, and priorities, and for soliciting, evaluating, and selecting MPS flight investigations.

The MPS Division maintains full visibility into project-level activities through participation in milestone reviews, receipt of regular and special reports, control of Level I changes, and informal information exchanges with all levels.

Integration and mission management activities associated with the operational implementation of MPS payloads on the STS will be the responsibility of the Spacelab Mission Integration Division, OSS, in NASA Headquarters and the assigned Mission Management Center, when applicable. The MPS Projects Office at MSFC will provide the necessary interface and support to the Mission Management Offices for initiation and execution of mission requirements. The MPS Projects Office will provide the Mission Manager with appropriate project data to assure successful integration of approved MPS payload systems into the STS and their operation as payloads. Level IV integration requirements for MPS payloads will be mutually agreed to by both the Mission and MPS Projects Managers. The MPS Projects


ADMINISTRATOR
DR. ALAN M. LOVELACE (ACT) A
DEPUTY ADMINISTRATOR
(VACANT)
ASSOCIATE ADMINISTRATOR/GENERAL MANAGER AD
DR. ALAN M. LOVELACE
ASSOCIATE DEPUTY ADMINISTRATOR ADB
ROBERT F. ALLNUTT
ASSISTANT FOR SPECIAL PROJECTS AX
DAVID WILLIAMSON
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PHILIP E. CULBERTSON
EXECUTIVE OFFICER AE
ANN P. BRADLEY (ACT.)
CHIEF SCIENTIST P
DR. JOHN E. NAUGLE (ACT.)
CHIEF ENGINEER D
DR. WALTER C. WILLIAMS
STAFF ADVISORS
DIRECTOR OF PUBLIC AFFAIRS LP-6
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WILLIAM E. LILLY
ASSOCIATE ADMINISTRATOR FOR MANAGEMENT OPERATIONS N
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ROBERT E. SMYLIE
AMES RESEARCH CENTER
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DRYDEN FLIGHT RESEARCH CENTER
EDWARDS, CA
GODDARD SPACE FLIGHT CENTER
GREENBELT, MD
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, AL
JET PROPULSION LABORATORY
(CONTRACTOR OPERATED)
PASADENA, CA
JOHN F. KENNEDY SPACE CENTER
KENNEDY SPACE CENTER, FL
LANGLEY RESEARCH CENTER
HAMPTON, VA
LEWIS RESEARCH CENTER
CLEVELAND, OH
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TX
WALLOPS FLIGHT CENTER
WALLOPS ISLAND, VA
NATIONAL SPACE TECHNOLOGY LABORATORIES
NSTL STATION, MS

FIGURE 31

272-78

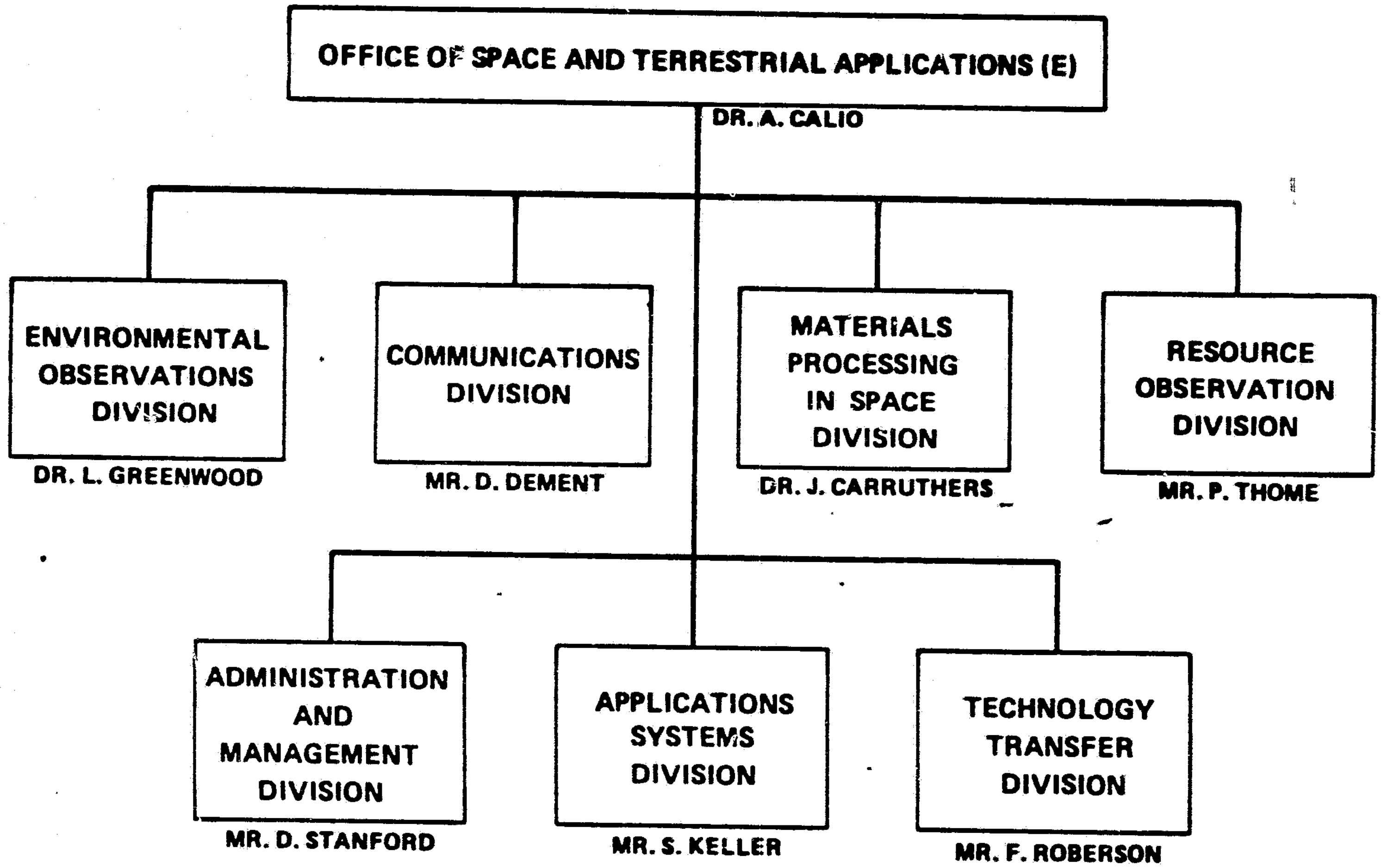


FIGURE 32

FUNCTIONAL CHART
MATERIALS PROCESSING IN SPACE

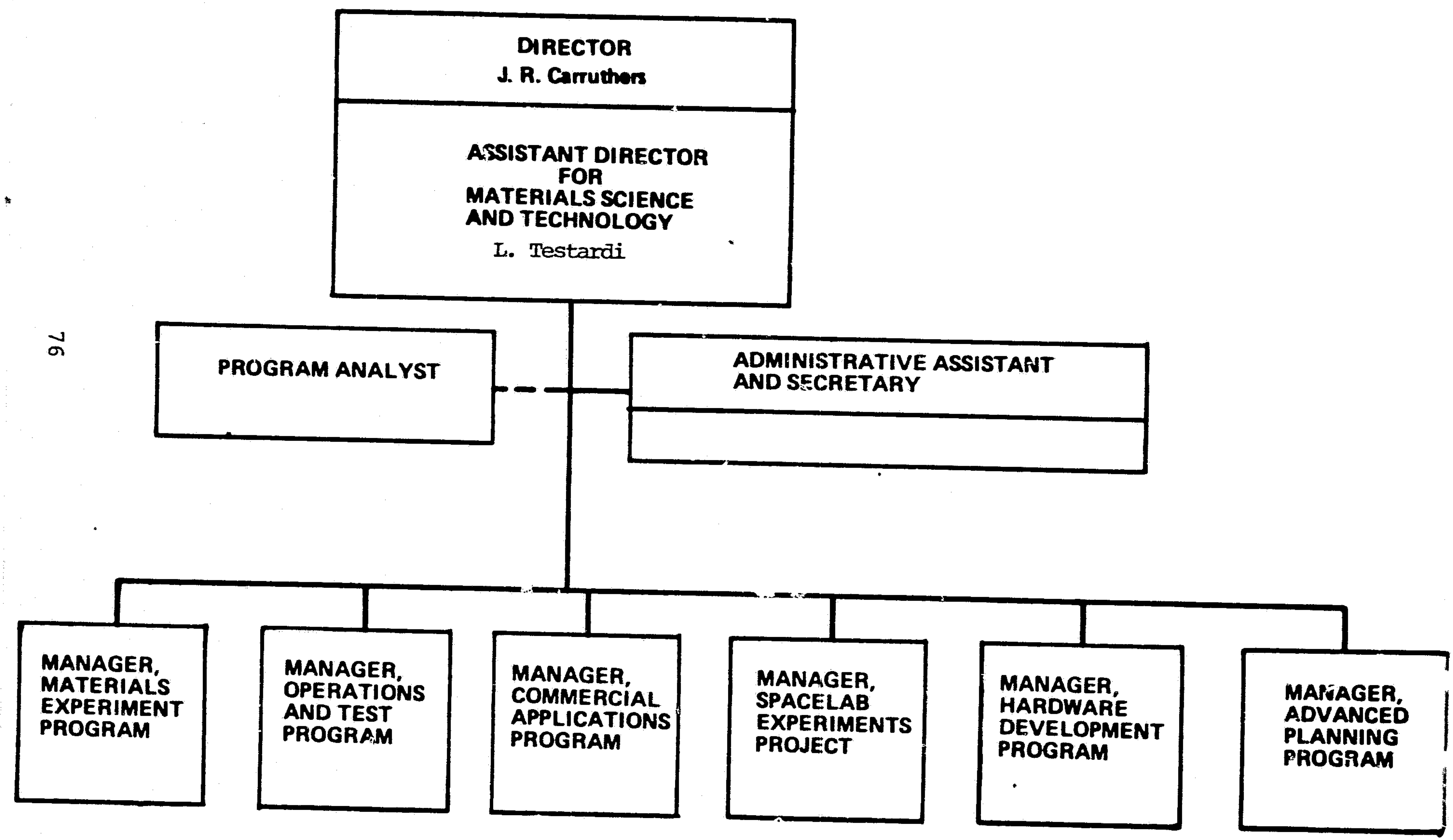


FIGURE 33

872-78

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GEORGE C. MARSHALL SPACE FLIGHT CENTER

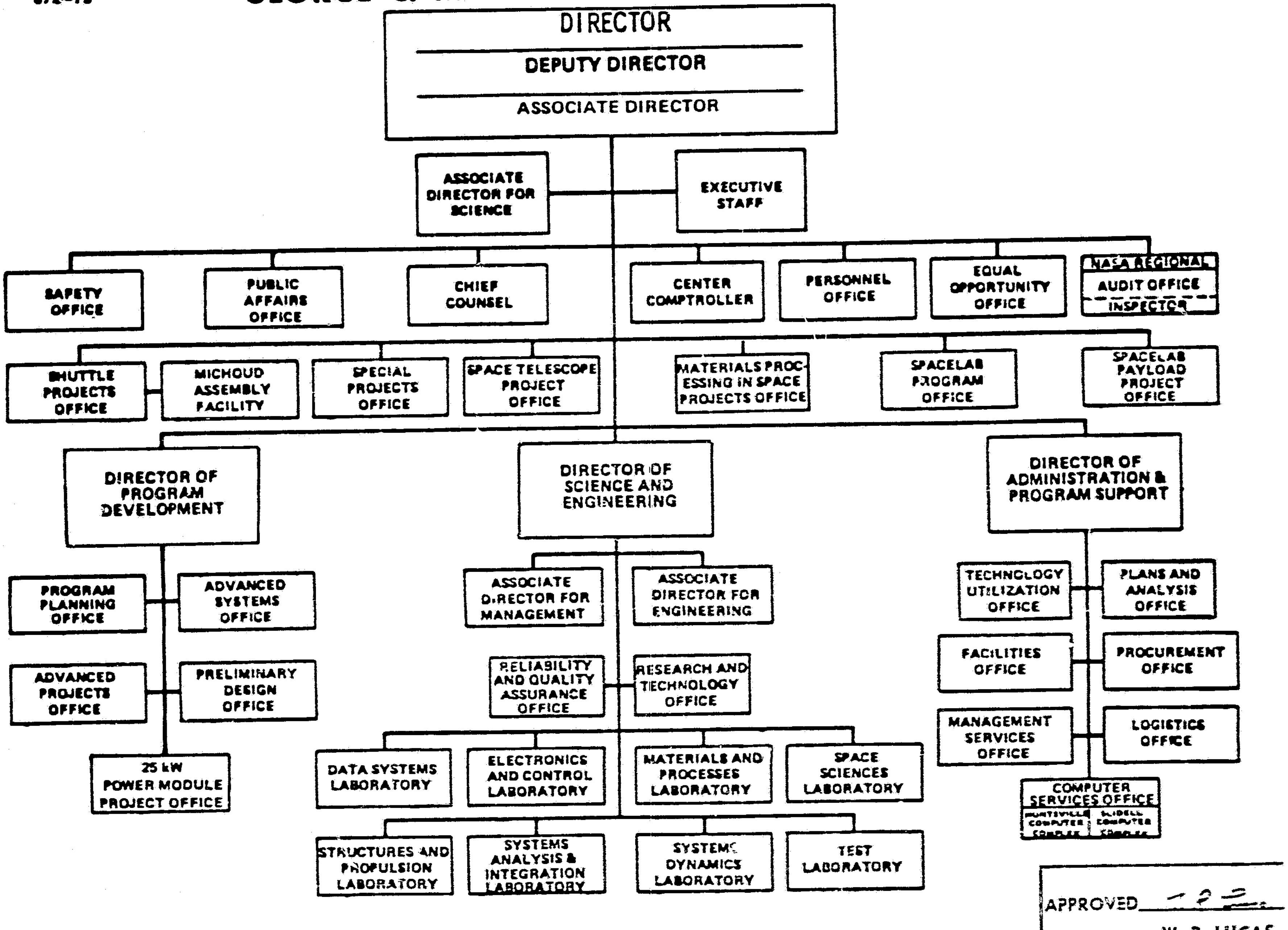
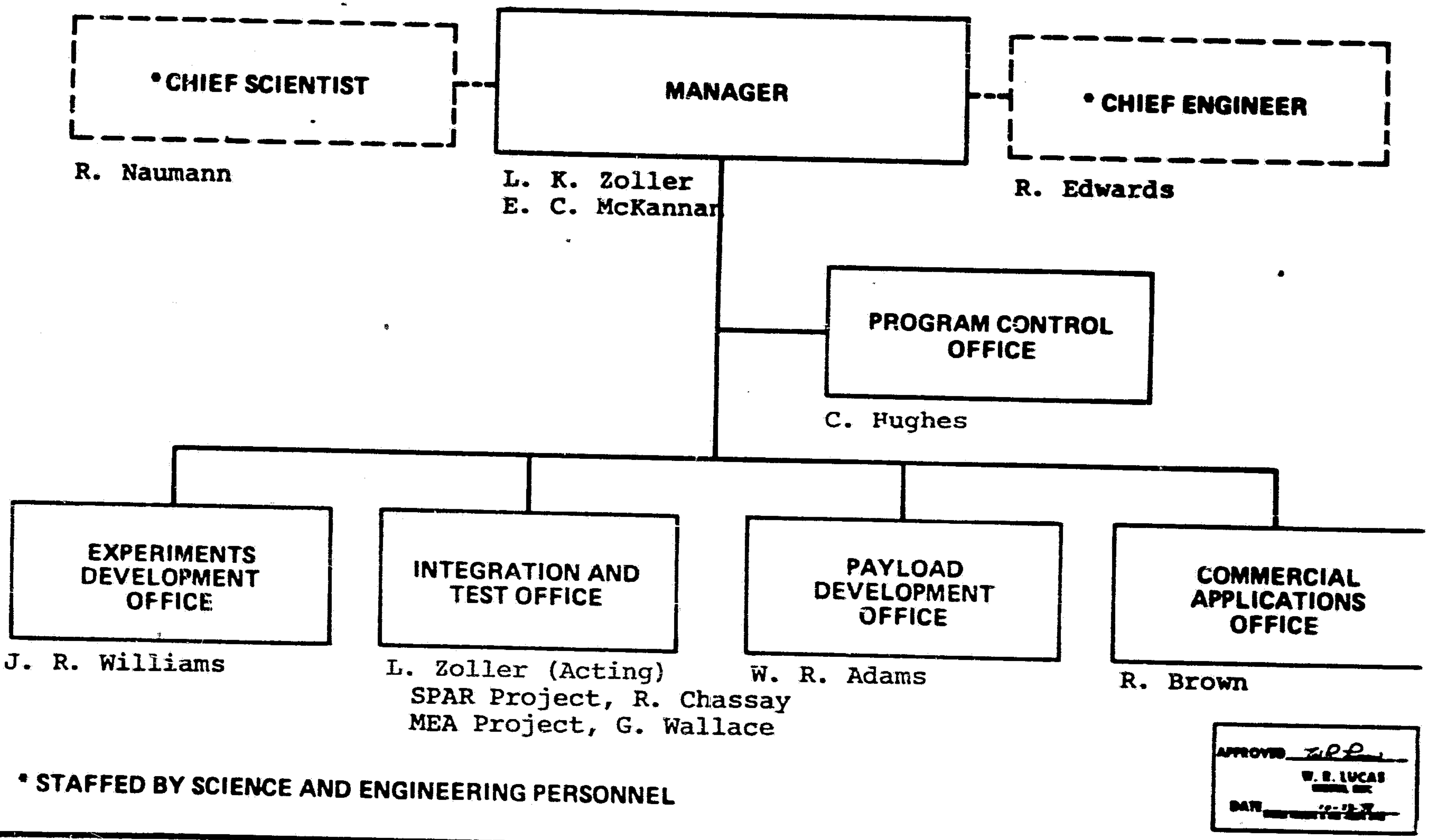


Figure 34

2454-78

MARSHALL SPACE FLIGHT CENTER
MATERIALS PROCESSING IN SPACE PROJECTS OFFICE



* STAFFED BY SCIENCE AND ENGINEERING PERSONNEL

FIGURE 35

Office will provide the Mission Manager with the launch site and flight requirements for MPS payload systems. MPS Projects Office will also furnish mutually agreed-to support for launch site integration, prelaunch and flight operations phase activities for operations involving MPS payload equipment. These services will be funded by the MPS budget.

Programmatic Interrelationships

MPS exhibits a strong intraprogram cohesiveness and logic that originate from the material processes which, due to gravity or vacuum dependency, can benefit from space applications. The basic characterization and applications of the material processes are being determined through a combined ground-based and space research and analysis effort. Facilitization for research and applicational needs is derived explicitly from the empirical requirements and, often, a broad complement of experimental payloads are employed; for example, a given series of investigations may utilize drop towers, aircraft parabolic flights, SPAR flights, MEA flights, Spacelab flights, and MEC flights in the accomplishment of the end objectives. The direct, coordinated involvement of academic, industrial, institutional, and government researchers and managers in all aspects of the program provides a continuous medium for review, evaluation, cross correlation, and program adjustment.

The relationship and interdependency of the MPS program to other NASA programs are typified by the following specific cases:

- Hardware and facilities developed by independent sources such as private industry in joint ventures with NASA may be flown in a limited number of demonstration missions as jointly arranged with the STS Operations Division of OSTS.

- MPS interface and functional requirements for the definition and design of the power system and corollary MEC will be coordinated with activities of the Advanced Programs Division of OSTS.

- Coordination and mutual support of basic research activities in the Materials Sciences will be continued with the Research and Technology Division of OAST. This will include direct participation of the Physics and Chemistry Experiments (PACE) Committee, funding of relevant RTOP's and coordination of activities in infrared detector materials, composite materials, and extraterrestrial materials processing.

- Coordination of bioprocessing activities with the Life Sciences Division of OSS will be continued with MPS emphasis on processing technology (methodology).

Substantial foreign activity in the space processing of materials is expected. NASA will establish cooperative ground-based research programs, coordinate the planning of advanced spaceflight capabilities, and share low-gravity spaceflight mission opportunities with foreign programs. In these ways, maximum use can be made of limited program resources.

Coordination and consolidation of research and applications planning activities are being pursued with various agencies and institutions, such as the Departments of Commerce, Defense, Energy, the National Bureau of Standards, the National Institutes of Health, and the Center for Materials Processing at MIT.

The integrated flow of the program is based on the following general interrelationships. The sounding rocket (SPAR) and aircraft microgravity flights are intended to provide relatively low cost, short preparation, investigative opportunities as precursory experiments to the much longer duration orbital flight opportunities afforded by the Shuttle. These activities will continue, at reduced frequencies with the operational availability of MEA. Precursory flight data will continue to be needed to finalize sample compositions and kinetic data, as well as for experiments that can be accomplished in the short flight time. There have been expressions of interest by parties to lease sounding rocket flights; thus, the capability of precursory flights must be retained in the program. The Orbiter middeck and MEA will provide a continuing mission of opportunity capability for MPS experiments; although the major thrust of NASA-sponsored research will ultimately shift to the Spacelab and free-flying MPS payloads, the simplicity and relatively low cost of MEA flights is very attractive for lease arrangements with private concerns as indicated by joint venture offers and inquiries. The Spacelab MPS payloads under development will accommodate research for many years, and new Spacelab experiments may be developed where manned involvement is essential and the Spacelab module can be used. The advent of an interim free flyer would permit adaptation of MEA experiments, Spacelab pallet payloads and certain commercial payloads for long duration orbital operations. When the power system becomes operational in the mid-80's, the Spacelab pallet experiments will be adapted for use in the MEC along with new experiment payload designed specifically for that purpose. The MEC will remain the primary MPS payload carrier for automated, long duration microgravity experimental and applications payloads. The MEC will, undoubtedly, be progressively upgraded to maintain

continuity with evolving requirements. The MEC is expected to provide the base for an aggressive, self-supporting commercial applications program. Subsequent to empirical demonstrations of the viability of the Molecular Wake Shield concept for creating localized ultrahigh vacuum conditions in near Earth orbit for practical MPS experimentation, the need for a major space vacuum facility may be established.

The overwhelming preponderance of the MPS program is to be accomplished through contracting and commercial joint ventures. The SPAR and MEA Projects are NASA inhouse projects although the experiment packages are, generally, contractor developed. MSFC has project responsibility for SPAR and MEA which includes inhouse design, development, assembly, scientific and experimental support, and post-flight data reduction; the Goddard Space Flight Center has responsibility for the SPAR sounding rocket integration and launch. MSFC has project responsibility for the remaining hardware elements although those activities are anticipated to be, in nearly all cases, contracted through competitive phased project planning selection processes. MSFC is responsible for the execution and administration of the flight experiments selected through established OSTA processes. Of those experiments already selected, 40 percent originated from colleges and universities, 35 percent from industry, 19 percent from NASA centers, and 6 percent from other agencies and institutions. An extensive ground-based SRT program and ATD program will be sponsored to meet the changing needs of the MPS program.

NASA—MSFC